CHANG'E 5 IS REWRITING LUNAR HISTORY p. 40

APRIL 2022

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ON THE COVER
Spiral galaxy M101 is just one of the tens of billions that formed after the early universe cooled and coalesced matter. This composite image shows it in multiple wavelengths. CHANDRA/HARVARD.EDU

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QUANTUM GRAVITY
Everything you need to know about the universe this month: JWST finally launches, more missing dark matter, and NASA's solar probe touches the Sun's corona.

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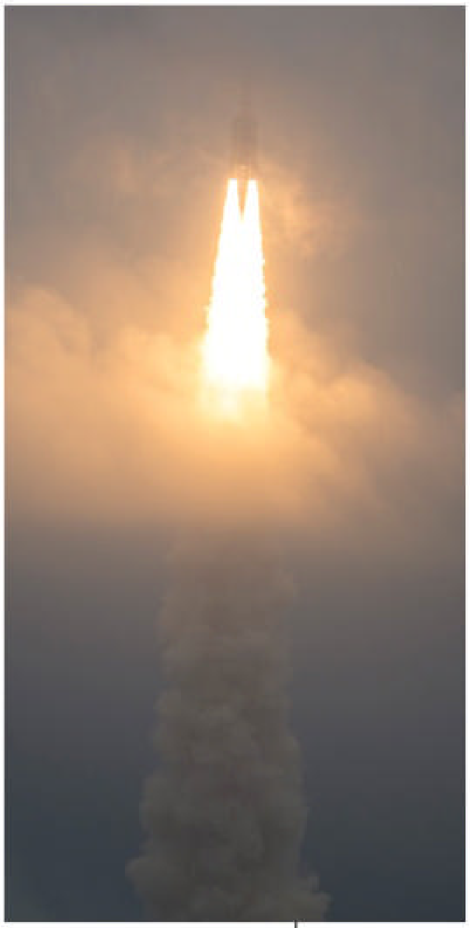
FROM THE EDITOR

A new era in space


The James Webb Space Telescope rockets to space, folded up inside the nose cone of an Ariane 5 rocket.
NASA/BILL INGALLS

On Christmas Day 2021, a very special and long-awaited event took place. The James Webb Space Telescope (JWST) was carried skyward by an Ariane 5 rocket from a pad in French Guiana. In essence the successor to the Hubble Space Telescope, JWST will inaugurate a new era in space. As I write this, astronomers and followers of the launch are mostly extremely relieved, as the complex process of unfolding and deploying the telescope is nearly complete. Exciting times seem to loom on the horizon.

The new telescope is on a significant journey. Rather than floating in low-Earth orbit, it will travel to the Second Langrangian Point, or L2. Parking the scope there will keep it in a stable, functional place while requiring no energy for it to move along with us in space. The telescope also needs to be kept protected, away from the Sun, the Moon, and Earth, so that it cannot absorb radiation from any of these bodies; L2 is some 1 million miles away from us.

JWST has a much larger mirror than Hubble's: Its 18 hexagonal mirror segments make up a primary mirror of about 6.5 meters aperture, which gives the telescope about 5.6 times greater light-gathering power than Hubble. Moreover, while Hubble is a near-ultraviolet, visible light, and near-infrared telescope, JWST is optimized for long-wavelength visible light through mid-infrared energy. This is critical because it will allow the new telescope to observe very distant objects that are too old and faint for Hubble.

The telescope will accomplish much. It will push boundaries with exoplanet discoveries. It will observe all manner of astrophysical objects, from comets to molecular clouds to active galaxies. Perhaps most importantly, if we're fortunate, the telescope should observe the earliest matter that formed after the Big Bang. It could sort what astronomers call the formation sequence of matter in the early cosmos. Did galaxies form first and then stars wink on within them? Did stars form and then accrete into galaxies? Did black hole "seeds" form and then galaxies gravitated around them? We don't know, but Webb may solve one of the greatest mysteries of cosmology. Stay tuned.

Yours truly,

David J. Eicher
Editor

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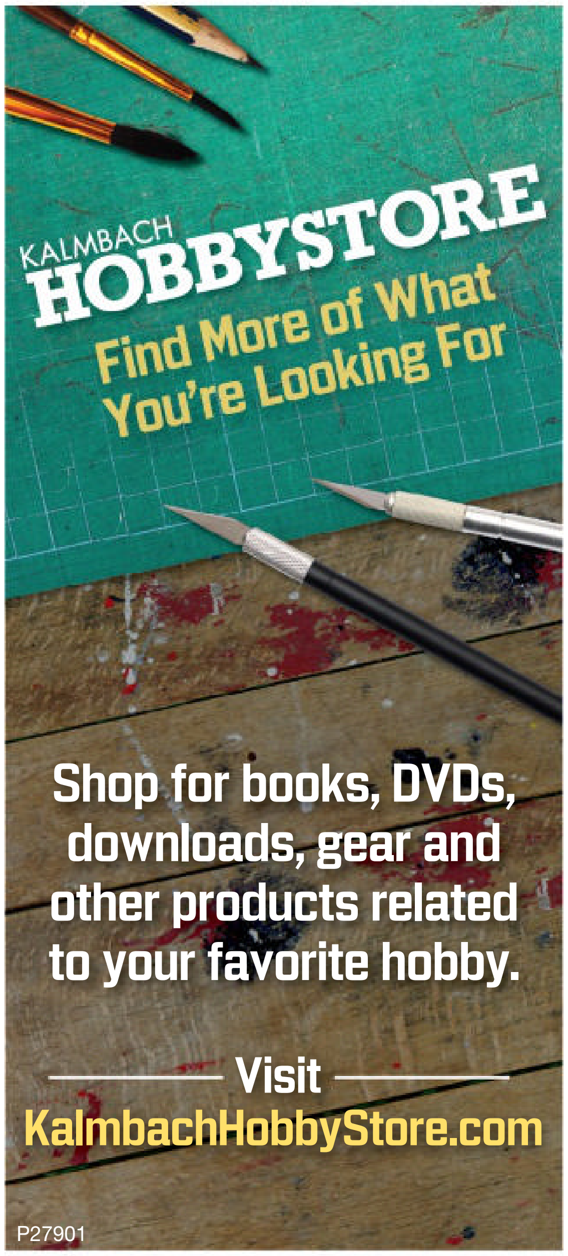

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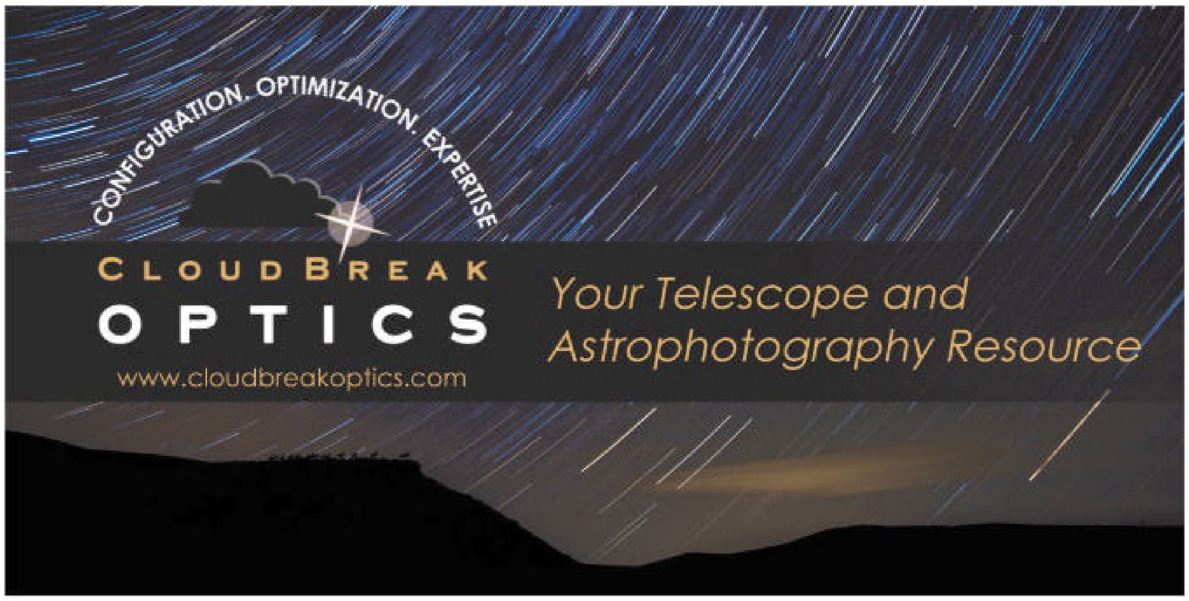

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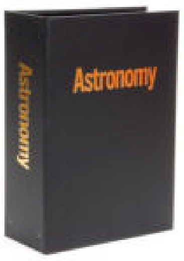

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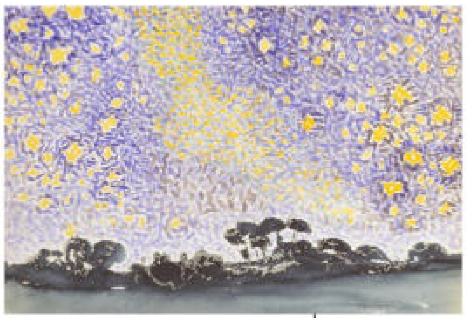

Few artworks used violet hues before "violettomania" overtook French Impressionists in the 1860s. ROBERT LEHMAN COLLECTION, 1975/THE METROPOLITAN MUSEUM OF ART

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to ***letters@astronomy.com****. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

The bridge between worlds

I just read Stephen James O'Meara's column about violet in the December 2021 issue. I am one of the two color scientists who worked with Allen Tager (the protagonist in the hunt for historical violet) on the investigation into the arts that were described. (You mention my name in the text, so thanks for that, of course.)

This article really makes me feel good. Since I was younger, I used to spend almost all my free time reading astronomy and observations. Therefore, your column bridges two worlds in my head that followed distant orbits. —**Eric Kirchner,** Senior Color Scientist, AkzoNobel

Theory vs. fact

It was so refreshing to read Bob Berman's "Alien life" (November 2021), where he challenged his fellow scientists, questioned cosmology's most basic assumptions, and described the universe's "sudden appearance as a hyper-dense marble-size ball that bewilderingly popped out of nothingness." While I might not agree with his other conclusions, as a university instructor I am continually appalled at the amount of theory and free-form speculation being bandied about to the public as "fact." I think it's all right for scientists to be bewildered enough on a topic to say, "We just don't know." I wish I saw that level of honesty more often in the scientific programming being presented to the public. —**John,** Lake Worth, FL

Leave it to chance?

I enjoyed reading Bob Berman's December 2021 article, "Chances are …" But I cannot agree with everything that he said. He seems to equate chance with randomness. I contend that these are two very different things. Randomness is a pattern of behavior; chance, on the other hand, is not even a thing. It's an ideological construct. The mere fact that our universe is governed by laws refutes chance events in nature. Berman touched on this when he said, "Once M42 exists, its chances of looking as it does become 100 percent! It's no longer unlikely in the least." Likewise, we can say, once the universe exists, its chances of looking as it does (including all evolutionary processes) become 100 percent; it's no longer unlikely. There is no room for chance in our universe. But there is plenty of room for discovery. —**Paul Kursewicz,** Epping, NH

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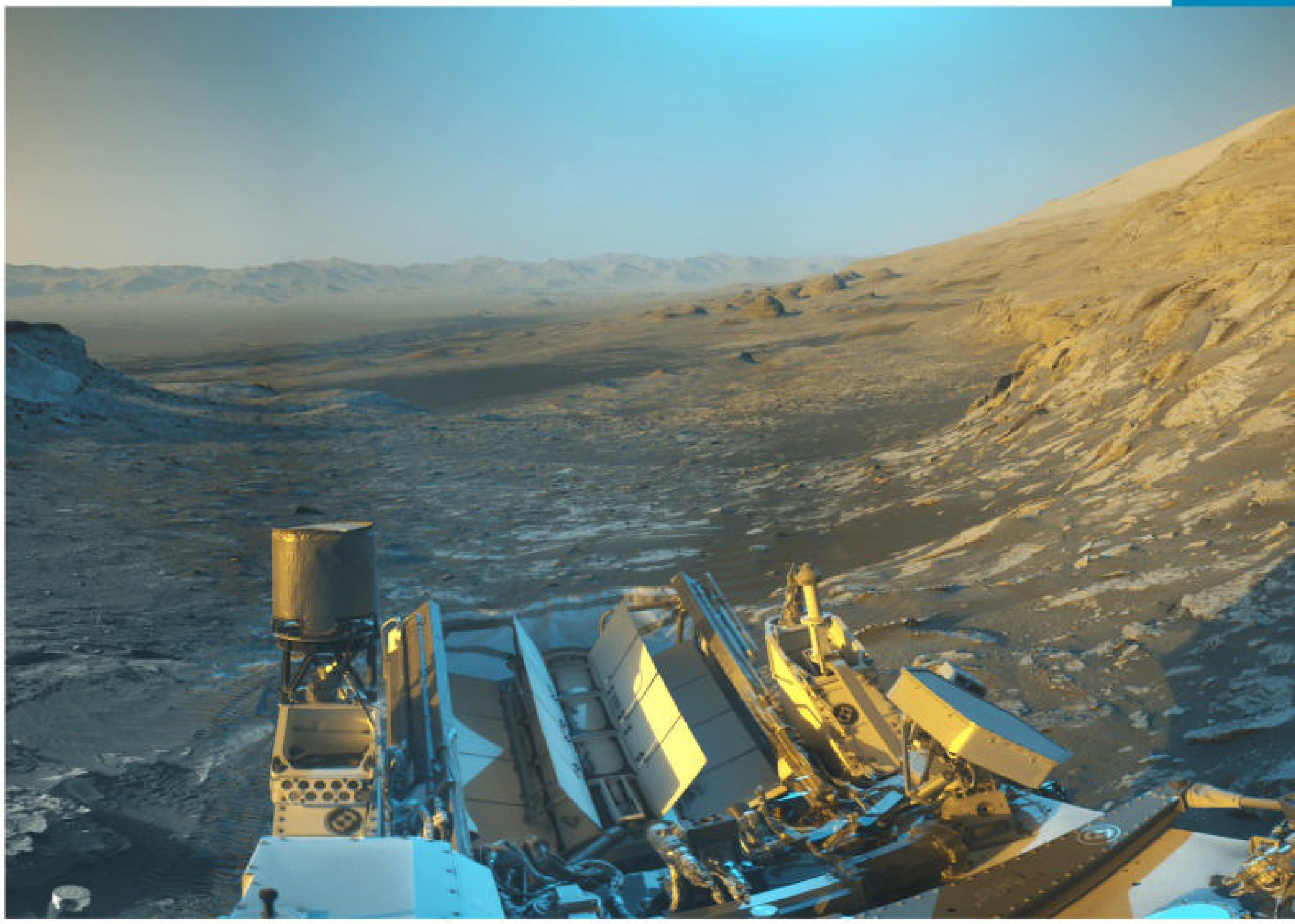
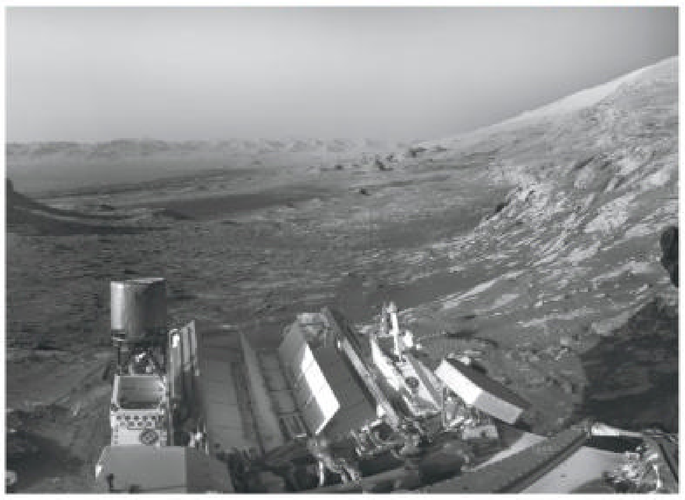
EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH

SNAPSHOT

A SHARP SCENE

Curiosity captures a martian landscape at two times of day.





In landscape photography, photographers must catch the light at just the right moment — or, in this case, moments. To produce the evocative colors and textures of this landscape, which shows Mars' Gale Crater and the lower slopes of Mount Sharp, the team behind NASA's Curiosity rover used a creative technique. First, they took two different black-and-white mosaics of the same scene at different times of day on Nov. 16, 2021 (at lower left and right). Then, they added orange to the morning picture and blue to the afternoon pictures — and green to both — and combined them to create an artistic rendition (top).

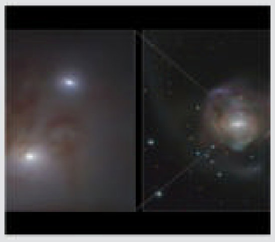
The effect mimics the natural tones in a sunlit scene. Orange morning light (from 8:30 A.M. local martian time) streams from the Sun at left, casting rays across the landscape at a low angle. This brings out detail in structures, like the sand dunes roughly a quarter of a mile (400 meters) away, and the hills that make up Gale Crater's rim about 20 miles (30 kilometers) in the distance. By contrast, light from the afternoon image (4:10 P.M. local time) comes from the upper right, filling in the morning shadows with cool, blue tones and revealing details that would otherwise be hidden in darkness. —MARK ZASTROW

NASA/JPL-CALTECH. BOTTOM FROM LEFT: SPP 1992 (PATRICIA KLEIN), ESO/VOGGEL ET AL.; ESO/VST ATLAS TEAM; ACKNOWLEDGEMENT: DURHAM UNIVERSITY/CASU/WFAU, NASA/BILL INGALLS

» HOT BYTES

A SPEEDY FEATHERWEIGHT

The newfound planet GJ 367 b, located some 30 light-years away, orbits its star in less than eight hours. The rocky world is also only half the mass of Earth, making it one of the lightest known exoplanets.



TIGHT-KNIT PAIR

At the heart of the galaxy NGC 7727 lurk two supermassive black holes. They are the closest pair to Earth and sport the smallest separation — just 1,600 light-years — of any duo yet found.

FILING TO FLYING

Mission Specialist Jessica Watkins launches aboard NASA's SpaceX Crew-4 mission this month. After starting at NASA as an intern, she will be the first Black woman to carry out a long-duration stay on the ISS.

JAMES WEBB SPACE TELESCOPE LAUNCHES

At long last, NASA's next-generation telescope soars to space.

LONG-AWAITED LAUNCH. The Ariane 5 rocket carrying the James Webb Space Telescope lifts off from French Guiana Dec. 25. NASA/BILL INGALLS

» Astronomers around the world received a great gift on Dec. 25, 2021: NASA's $10-billion James Webb Space Telescope (JWST) rode safely to space on an Ariane 5 booster from Europe's Spaceport in Kourou, French Guiana.

The liftoff at 7:20 A.M. EST was a milestone for the flagship telescope designed to capture light from the first galaxies and characterize alien worlds. It also marked the end of a decades-long development full of delays and cost overruns.

But it was only the beginning of what NASA officials called "29 days on the edge." That's how long it took the telescope to reach its destination, the L2 Lagrange point, nearly 1 million miles (1.5 million kilometers) from Earth, where the gravity of the Sun and Earth align to keep an object's orbital position relative to them roughly stationary.

The telescope had been designed to fold up to fit inside the rocket's nose cone, and the riskiest part of bringing it online was the intricate process of unfolding itself. Over the course of two weeks, JWST's team instructed the telescope to deploy its components step-by-step — first the telescope's supporting structures, then its sunshield, and finally, its secondary and primary mirrors. At one point, they paused for two days to better understand the thermal characteristics of the telescope.

When the final segment of the primary mirror was locked into place Jan. 8 at 1:17 P.M. EST, engineers in the telescope's control room at the Space Telescope Science Institute in Baltimore cheered and traded fist bumps — and astronomers breathed a sigh of relief.

"We're on an incredible high right now," said Bill Ochs, JWST's project manager, at a press conference. "Today represents the beginning of a journey for this incredible machine, to its discoveries that we'll be making in the future."

DELAYS TO THE LAST

JWST originated in a 1996 report by a panel of astronomers attempting to plan the Hubble Space Telescope's successor. It was originally envisioned to launch in

NEXT STOP, L2. After separating from the upper stage of its Ariane 5 booster shortly after launch, JWST (the silver object at left) is now on its way to its final orbit. NASA

2007 with a 4-meter mirror and a cost of $500 million.

After 14 years of delays and a ballooning price tag that, at times, threatened to swallow NASA's astrophysics budget whole, JWST emerged as the most powerful space telescope ever built. It is a joint project of NASA, the European Space Agency, and the Canadian Space Agency.

Its 6.5-meter hexagonal, segmented mirror is shielded from the heat of the Sun by a five-layer sunshield that will allow the telescope to cool to –370 degrees Fahrenheit (–223 degrees Celsius). These frigid conditions will minimize background noise at the infrared wavelengths JWST is designed to observe, allowing the telescope to seek the redshifted light of primordial galaxies and penetrate the dusty shrouds of nebulae to see young stars.

NORTHROP GRUMMAN

PACKING UP. JWST underwent final deployment tests in late 2020. NASA/CHRIS GUNN

For some astronomers, who have much riding on JWST — including observing proposals already accepted and planned — the approaching launch brought a sense of foreboding. Repeated delays pushed the launch closer to the end of 2021, adding another layer of stress to a holiday break already thrown into havoc by the omicron variant of COVID-19.

JWST had arrived Oct. 12 via cargo ship at the spaceport in French Guiana, on schedule for a Dec. 18 launch date. This slipped to Dec. 22 after a band suddenly unclamped itself during launch preparations and jolted the entire observatory, requiring additional checks. Then, a communications problem from the telescope to ground support arose; it was traced to a bad cable and pushed the launch to Dec. 24. Finally, bad weather forced a postponement to the morning of Dec. 25.

The euphoria of launch was tempered by the knowledge that the technically audacious deployment lay ahead. An engineering review had identified 344 potential ways the process could fail — three times as many as a Mars landing. But NASA's bet seems to have paid off.

The team must next align JWST's mirrors and commission its instruments. The scope's first images should come six months after launch. —M.Z.

QUICK TAKES

NEW TO THE AREA

Some 40 local dwarf galaxies are moving too fast to be satellites to the Milky Way, according to data from ESA's Gaia mission. Instead, it's likely these galaxies just arrived in our neighborhood in the last few billion years.

POCKET-SIZED LIFE

A new theory for how seemingly inhospitable Venus could support life suggests that organisms may produce pockets of ammonia in the clouds. These pockets would set off a snowball effect, neutralizing the surrounding sulfuric acid so life could thrive.

HUBBLE SAVED (AGAIN)

NASA's Hubble Space Telescope entered safe mode for the second time in 2021 on Oct. 25, after the loss of specific data synchronization messages. The 31-year-old telescope returned to full science operations Dec. 6 when the team reactivated its final instrument.

DEFINING A PLANET

A new study proposes that a body should be considered a planet if it once was or currently is geologically active. According to the researchers, requiring a body to have cleared its orbit — the current International Astronomical Union definition — may be too narrow for future exoplanet discoveries.

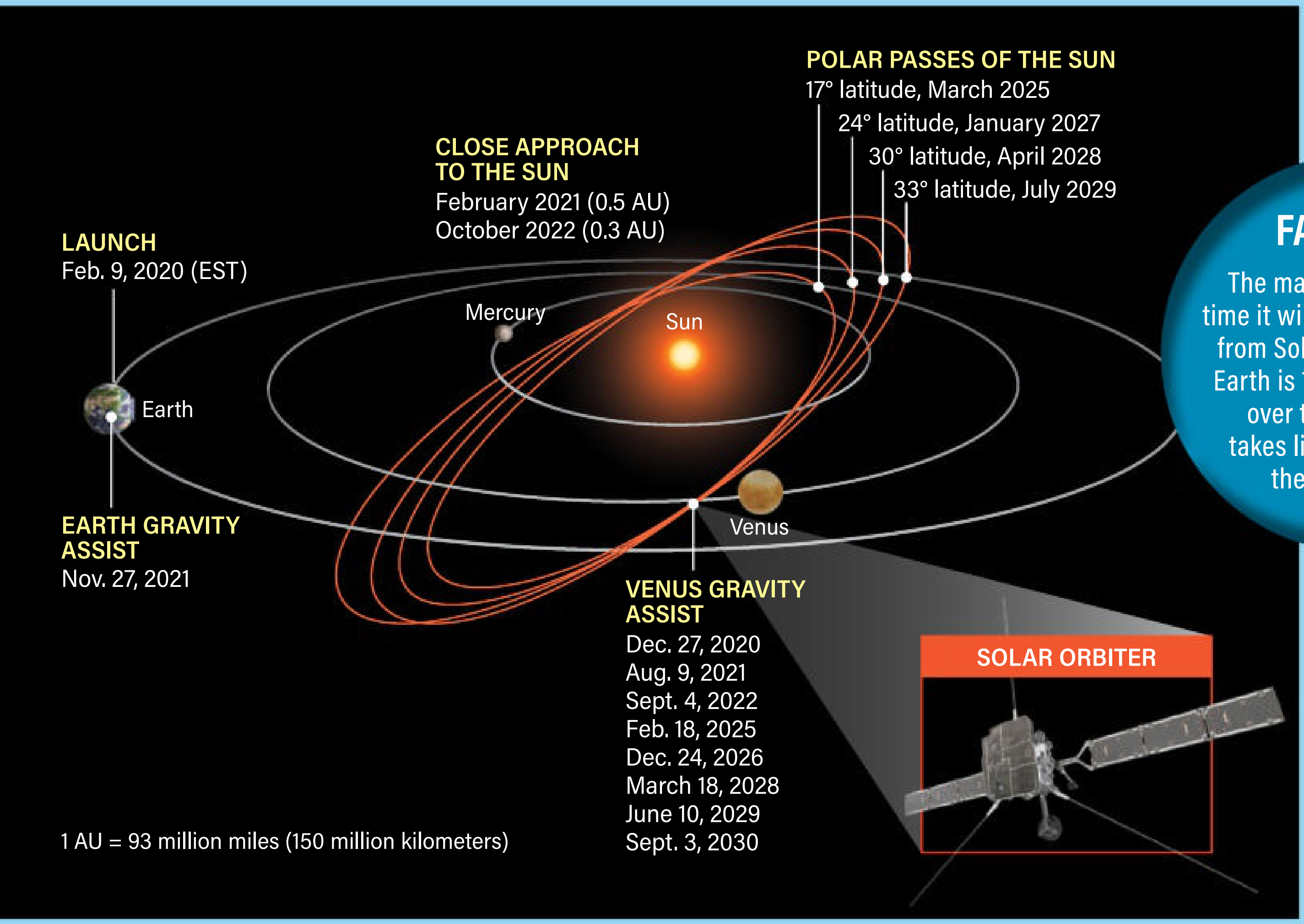
X-RAY GLASSES

On Dec. 9, NASA and the Italian Space Agency launched the Imaging X-ray Polarimetry Explorer mission. The observatory will measure the polarization of X-rays from the most extreme objects in the universe, including supernova remnants and supermassive black holes.

SNEAKY JUPITER

Citizen scientists recently spotted an object that sits more than 1,600 times farther from its star than Earth is from the Sun. Either a large Jupiter or a small brown dwarf, the object was missed by previous professional searches. —CAITLYN BUONGIORNO

SOLAR ORBITER'S POLAR APPROACHES


POLAR PASSES OF THE SUN
17° latitude, March 2025
24° latitude, January 2027
30° latitude, April 2028
33° latitude, July 2029
CLOSE APPROACH TO THE SUN
February 2021 (0.5 AU)
October 2022 (0.3 AU)
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Feb. 9, 2020 (EST)
Mercury
Sun
Earth
EARTH GRAVITY ASSIST
Nov. 27, 2021
Venus
VENUS GRAVITY ASSIST
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Aug. 9, 2021
Sept. 4, 2022
Feb. 18, 2025
Dec. 24, 2026
March 18, 2028
June 10, 2029
Sept. 3, 2030
SOLAR ORBITER
1 AU = 93 million miles (150 million kilometers)

ASTRONOMY: ROEN KELLY

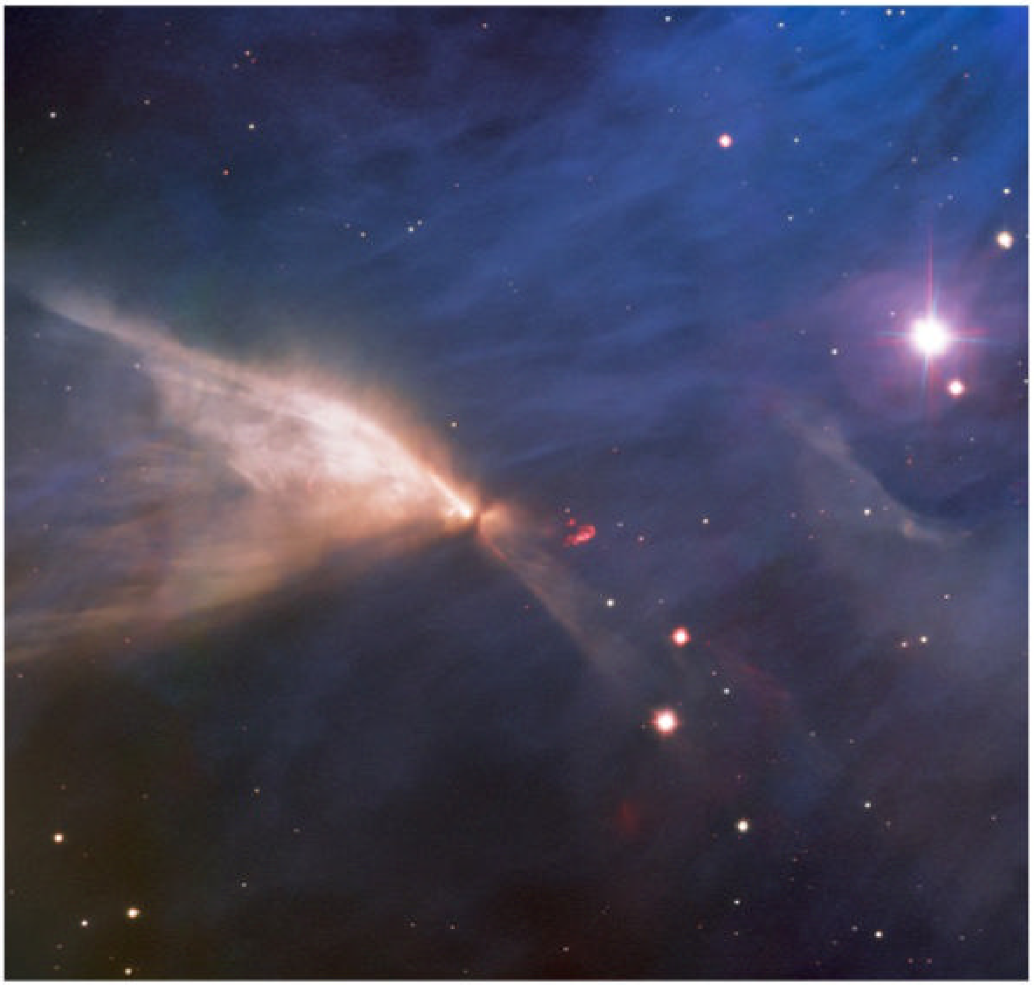
Pump it up. In November 2021, the European Space Agency and NASA's Solar Orbiter passed Earth for a gravity assist that also kicked off its main mission to study the Sun. The spacecraft is now on its way to a close approach in October 2022, when it will come within 0.3 astronomical unit (AU) of our star — roughly one-third the average Earth-Sun distance. From there, Solar Orbiter will continue occasionally passing Venus, using the planet's gravity to bump up its orbital inclination. In March 2025, the craft will make its first observation of the Sun's poles, starting at 17° latitude. And if all goes well, Solar Orbiter will start its extended mission in December 2026, continuing its up-close exploration of the Sun's never-before-seen polar regions with more passes at even higher latitudes. —ALISON KLESMAN

FAST FACT

The maximum amount of time it will take a radio signal from Solar Orbiter to reach Earth is 16.5 minutes — just over twice the time it takes light to travel from the Sun to Earth.

Cosmic butterfly sports one wing

Star formation is neither quiet nor calm. Often, young stars blow out streamers of gas and dust even as they contract and pull material around them. One example of this turbulent period is in the Chamaeleon Infrared Nebula, located within the larger Chamaeleon Complex of star-forming clouds in the southern sky. At the center of the nebula is a young star, hidden from view by a dark band of cold dust that is likely an edge-on circumstellar disk. Such disks are where planetary systems form. To the left of the disk in this image stretches a bright, broad outflow of gas from the star, resembling a butterfly wing. But this cosmic insect has only one such appendage — on the other side is a compact, red-colored glow where the fast-moving gas from the star is striking more sedate gas floating within the larger nebula. The soft blue glow lighting the entire scene is reflected light from a different, nearby star not imaged here. —A.K.



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Compliments to the chef

Like any happy eater, our Milky Way's supermassive black hole, Sagittarius A* (Sgr A*), belches every time it consumes a particularly hefty meal. The resulting small outbursts, or mini-jets, can be difficult to spot outright, but may leave traces in the surrounding gas. Such evidence of a blowtorch-like jet released just a few thousand years ago was outlined in a paper published Dec. 6 in *The Astrophysical Journal.* Though the jet wasn't spotted directly, the Hubble Space Telescope instead saw indirect evidence of the jet's material pushing on a nearby hydrogen cloud. Another lingering jet was previously spotted in 2013 by NASA's Chandra X-ray Observatory and the Karl G. Jansky Very Large Array. Both jets clearly indicate that the 4.1-million-solar-mass Sgr A* is far from a sleeping giant. – C.B.

NASA, ESA, AND GERALD CECIL (UNC-CHAPEL HILL); IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI)

NEWFOUND PLANET'S HOST STARS ARE MOST MASSIVE YET

Astronomers have directly imaged a planet orbiting a pair of stars so massive that they challenge our ideas of how planets and stars form.

That stellar duo is the binary system b Centauri, located some 325 light-years away. (Though visible to the naked eye at magnitude 4, it is not to be confused with Beta [β] Centauri, one of the brightest stars in the sky.) Its newfound planet was captured by the Very Large Telescope at the European Southern Observatory in Chile, and reported Dec. 8 in *Nature*.

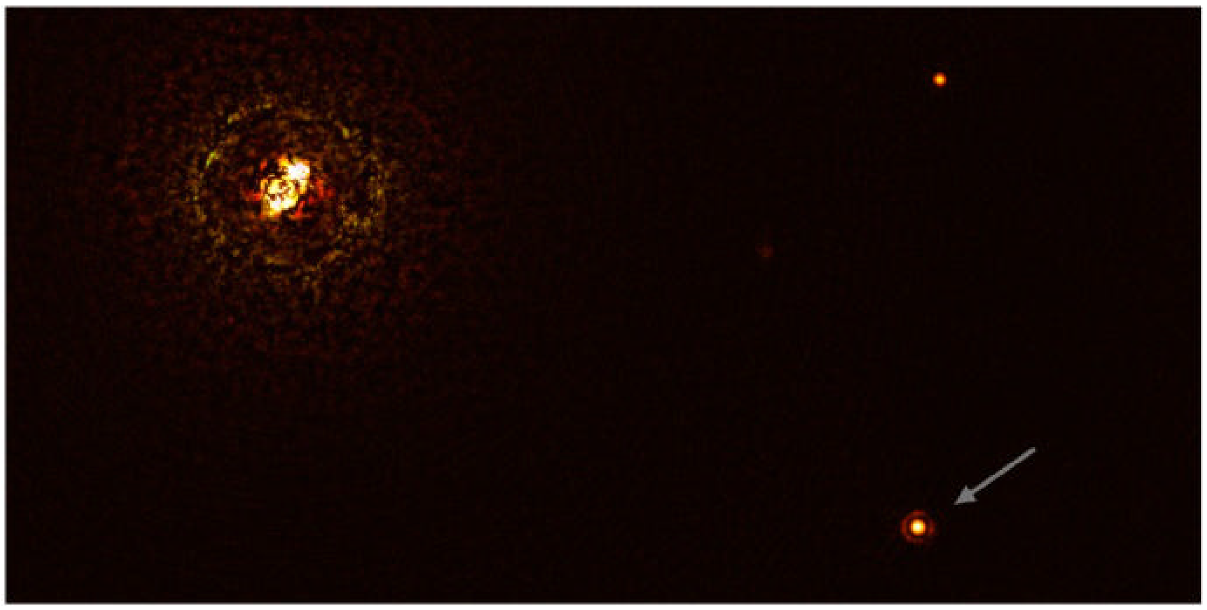
By convention, the first discovered planet in a system is given the suffix b, earning this planet the unusual name of b Centauri b. It's a gas giant roughly 11 times as massive as Jupiter, orbiting its host stars at a distance roughly 560 times that of Earth from the Sun.

But those host stars make this system unlike any yet found: They have an estimated combined mass of six to 10 times that of the Sun — at least twice the mass of any other star or stars confirmed to host a planet. And the system's larger star is spectral type B, the second-hottest type. Stars that hot emit powerful ultraviolet and X-ray radiation, which should disrupt the planet-forming process.

Finding b Centauri b "completely changes the picture about massive stars as planet hosts," said team leader Markus Janson, an astronomer at Stockholm University in Sweden, in a press release.

The key to forming a planet around massive stars may differ from the conventional model, in which dust grains surrounding the fledgling star begin glomming on to each other. This process of accumulation eventually snowballs, forming a planetary core and, if it's large enough, collecting gas to form an atmosphere.

But perhaps a planet like b Centauri b formed through a top-down process, more like a star: There may have been enough surrounding gas left over from the star's formation that some of it eventually collapsed under its own weight, directly forming a planet. – M.Z.



B TEAM. The apparent rings around the b Centauri binary star system (left) and its planet (right; marked by arrow) are artifacts from the coronagraph used to block out light from the host stars, reducing their glare. The object at top right is a background star. ESO/JANSON ET AL.

1/5 The fraction of early galaxies scientists believe are still hidden from current telescopes by cosmic dust.

NASA grazes the Sun

For the first time, humanity has touched the Sun. On April 28, 2021, NASA's Parker Solar Probe — different from Solar Orbiter (page 10) — traveled through our star's corona. While in the outermost part of the solar atmosphere, Parker sampled coronal particles and measured magnetic fields.

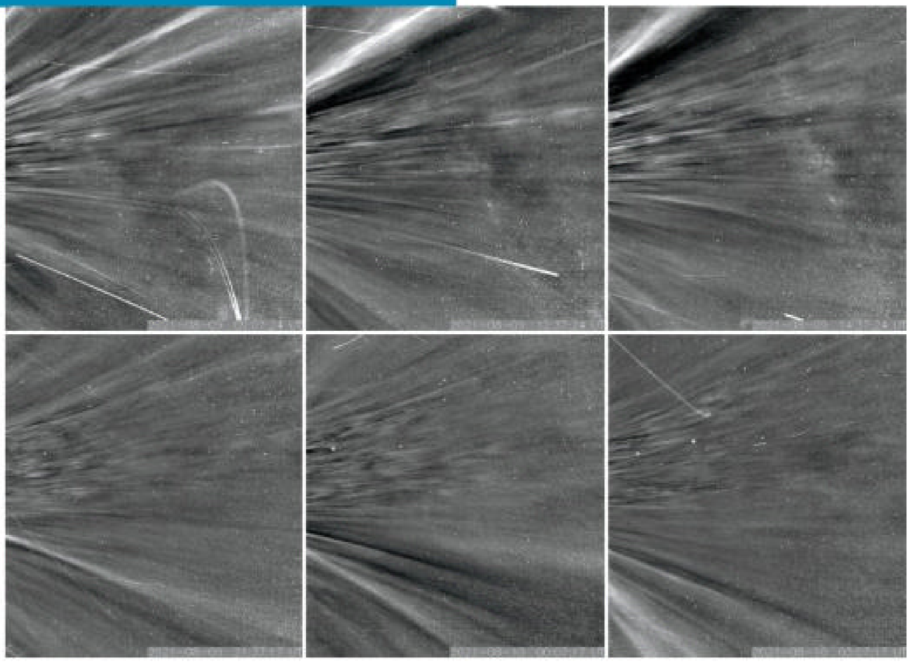
To accomplish the feat, Parker used gravitational assists from Venus during four flybys to gradually direct it closer to our star.

Since its launch in 2018, researchers have waited to see when Parker would cross the Alfvén critical surface. This marks the boundary where particles in the corona escape the Sun's gravity and become the solar wind — the stream of charged particles flowing from our star. Previously, astronomers estimated this point was about 4.3 million to 8.6 million miles (6 million to 13.8 million kilometers) from the Sun's visible surface. Parker finally crossed the boundary last April, placing the Alfvén critical surface at 8.1 million miles (13 million km).

Parker's encounter was not a smooth one. The probe passed in and out of the corona several times, indicating the boundary has spikes and valleys rather than forming a smooth halo around our star. Eventually, scientists may be able to trace these wrinkles back to regions of solar activity on the surface of the Sun, a critical step for researchers looking to reliably predict disruptive events like coronal mass ejections.

Parker will make three more Venus flybys that will bring the probe even closer to the Sun. By the end of its mission in 2025, it will pass within 3.8 million miles (6.2 million km) of the photosphere.

"I'm excited to see what Parker finds as it repeatedly passes through the corona in the years to come," said Nicola Fox, director of NASA's heliophysics division, in a press release. "The opportunity for new discoveries is boundless." — C.B.



CELEBRATION. On its encounter with the corona in August 2021, the Parker Solar Probe flew by coronal streamers, which until now have only been seen from afar. The structures can be seen in the upper portion of the top row of images and the lower portion of the bottom row of images. NASA/JOHNS HOPKINS APL/NAVAL RESEARCH LABORATORY

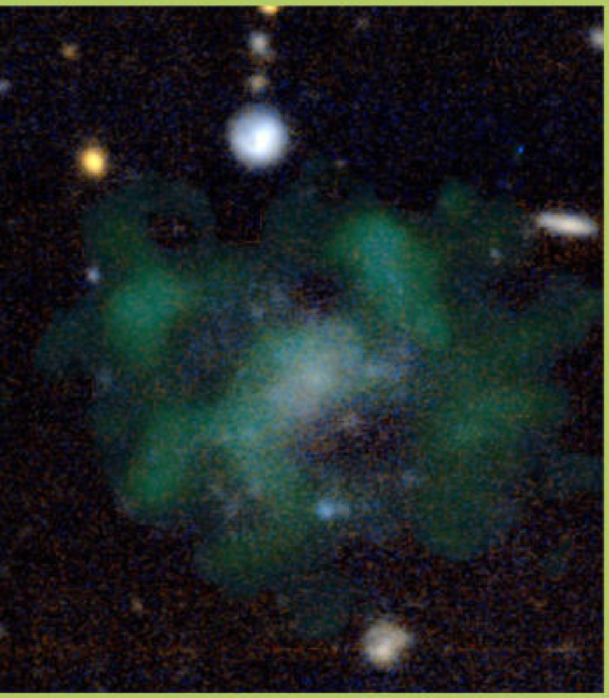
MORE MISSING DARK MATTER

The debate over galaxies without dark matter has returned. In 2018 and 2019, a series of studies lead by astronomer Pieter van Dokkum of Yale University made the case that two galaxies — NGC 1052-DF2 and NGC 1052-DF4 — are devoid of dark matter, an invisible substance that only gravitationally interacts with regular matter. Because every other well-studied galaxy seems to be chock-full of dark matter, the proposed dearth of it within DF2 and DF4 didn't sit well with many astronomers. Now, although the debate is still not settled, new research lends credence to the dark-matter-less camp.

The new evidence comes from a study published Dec. 14 in *Monthly Notices of the Royal Astronomical Society.* In it, researchers examined a galaxy named AGC 114905, which, like DF2 and DF4, is an ultra-diffuse galaxy roughly the size of the Milky Way. However, AGC 114905 contains only around one-thousandth the number of stars as our home galaxy. To determine whether this galaxy hosts copious amounts of dark matter, the researchers spent 40 hours using the Very Large Array in New Mexico to measure how quickly neutral hydrogen gas orbits around the center of AGC 114905. If there is dark matter spread throughout, gas that's far from the galaxy's core should still rotate quickly. However, if there is no dark matter, the tenuously bound gas near the galaxy's outskirts should move at a more leisurely pace.

The researchers found that the motions of the hydrogen gas within AGC 114905 can be completely explained if the galaxy only contains mass from the normal matter visible within it. And so far, the team hasn't been able to identify a plausible explanation for why there is no dark matter.

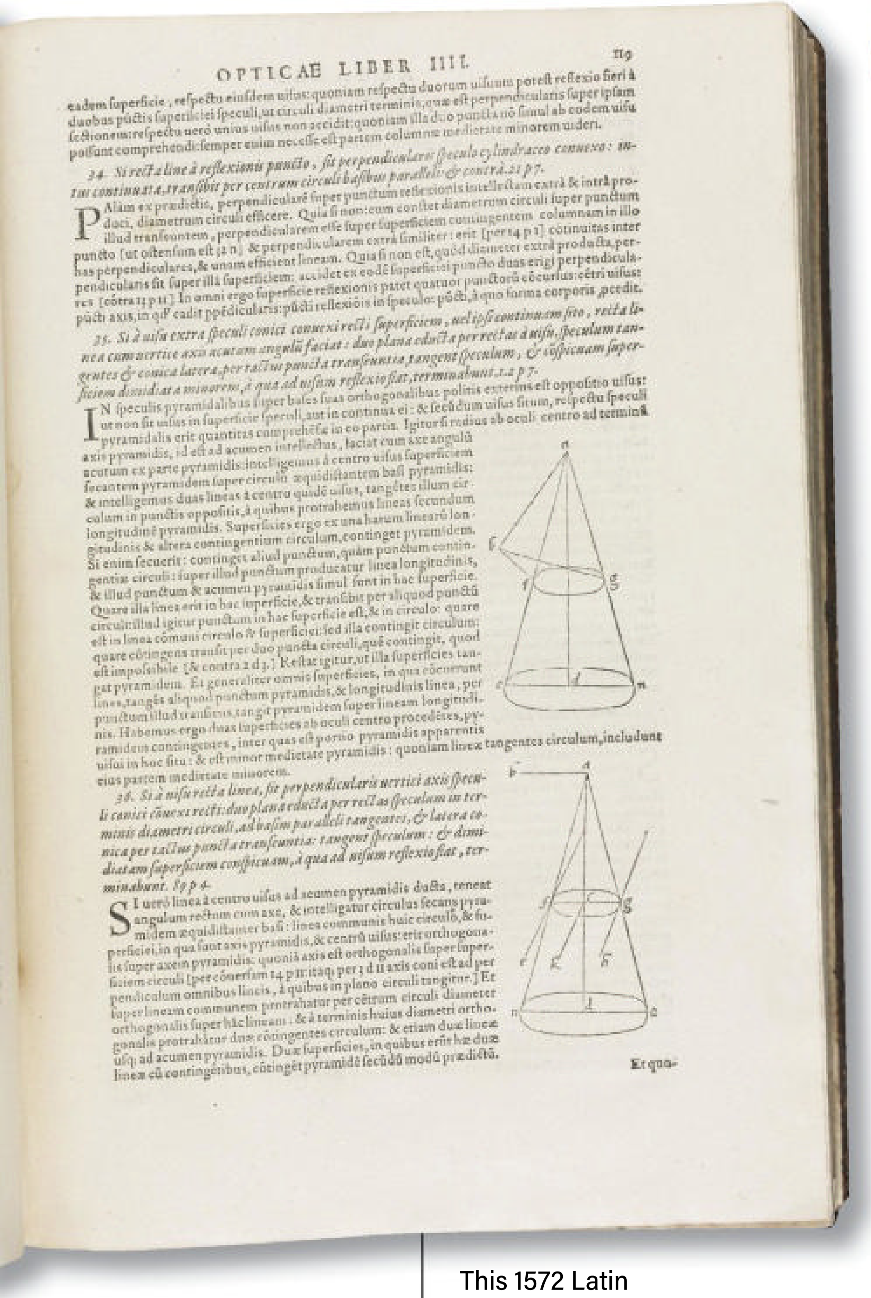
Stay tuned, because this saga is surely far from over. — JAKE PARKS



MISSING: DARK MATTER. Despite 40 hours of scrutiny with state-of-the-art telescopes, the galaxy AGC 114905 appears to lack any appreciable amount of dark matter. The galaxy's neutral hydrogen gas is shown in green, while visible stars appear blue. JAVIER ROMÁN & PAVEL MANCERA PIÑA

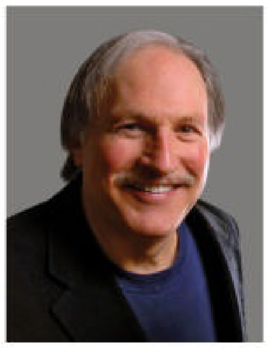
Men with glass

Explore the legacy of an ancient astronomer you've probably never heard of.



This 1572 Latin edition of Alhazen's *Book of Optics* includes the astronomer's original diagrams.

OPTICAE THESAURUS ALHAZENI ARABIS LIBRI SEPTEM, FROM THE OU LIBRARIES DIGITAL COLLECTIONS, HISTORY OF SCIENCE COLLECTION, HTTPS://REPOSITORY.OU.EDU



BY BOB BERMAN

Bob's recent book, Earth-Shattering (Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.

Of the world's countless material objects, you and I probably have one in common. We each own at least one lens. They're in all our eyepieces.

The word *lens* arrives unchanged from its Latin origins, where it means "lentil." And the double-convex shape of every lentil bean really does resemble that of lenses. Yet few of us know of Alhazen, who wrote one of history's most influential works on the subject, the seven-volume *Book of Optics*. No surprise: We're mostly clueless about science before the Renaissance.

Let's focus on that mystery man who fashioned so many revelations during the Golden Age of Arabic Science. Abu Ali al-Ḥasan ibn al-Haytham was born in Basra (in what is now Iraq) in A.D. 965. Here, though, we'll use his Latinized title — Alhazen. In a groundbreaking approach, he performed careful experiments, applied rigid mathematics, and made watchful observations. For example, in 1021 (or thereabouts — the exact date is disputed) Alhazen became the first to accurately describe the way air bends, or refracts, light. He showed how our atmosphere creates twilight and said the first trace of dawn begins when the Sun is 19° below the horizon. Today's modern figure is 18°.

Alhazen employed complex, accurate geometric calculations to determine the height of Earth's atmosphere is 52,000 passuum. You're not impressed? That probably means you haven't used that Latin unit of length lately. It was equal to about 5 feet (1.5 meters). Do the math and Alhazen's figure for our atmosphere's height — how far up the air extends — was 49 miles (79 kilometers). Nowadays, most authorities place the figure at 52 miles (84 km), the top of the mesosphere.

In addition to discovering the laws of refraction, Alhazen also invented the pinhole camera and dispersed light into its constituent colors. He was an expert in eclipses and optics and correctly figured out the math behind them.

How he had time for so much experimentation is a strange story that began when he still lived in Basra and read about the Nile's famous annual floods. In a moment of overconfidence, he wrote that the river's destructive autumn inundations could easily be controlled by a system of reservoirs and dikes, which might also serve to store the water for use during the long dry season.

When he arrived in Cairo, the caliph — by all accounts a testy, unpleasant fellow — summoned him and said, "OK, do it." Alhazen was taken on a tour of the various floodplains. He must have shuddered. Observing the flood regions in person, the pragmatic Alhazen immediately knew that his now-famous published plan could not possibly work, not in a million years. What happened next is hazy. But by some accounts, rather than admit his mistake and take a chance that the murderous Caliph would have him executed on the spot, Alhazen tried a risky ploy: He feigned madness.

The ruler then locked him under permanent house arrest. This gave Alhazen 10 full years, starting in 1011, to write innumerable brilliant treatises, including the notable work on optics that ranks with that of Newton seven centuries later. He was finally set free when the caliph died in 1021 and Alhazen could shake off the crazy act that he had probably gotten pretty good at.

We're mostly clueless about science before the Renaissance.

Of course, the field of optics was still in its infancy. But its development would ultimately allow Galileo Galilei to use a telescope to view the heavens. What's more, by selling homemade telescopes, Galileo made a nice profit from a successful optics-related side business. That's a lesson poor Alhazen, whose brilliance failed to lift him out of the raccoon tax bracket, never seemed to learn — even if his mesmerizing pinhole camera drew amazed visitors to his door.

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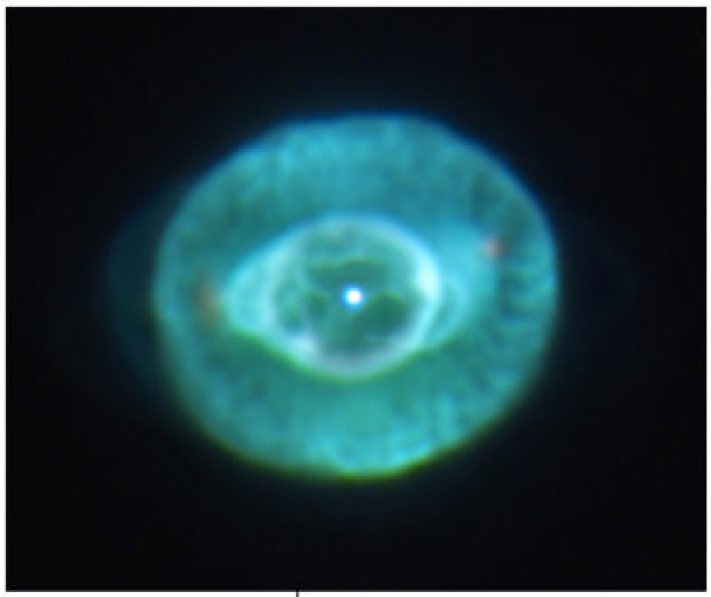
BINOCULAR UNIVERSE

Hiding in Hydra

Turn your eyes to the sea serpent's glittering scales this spring.



NGC 3242 is an eerie sight for observers. Nicknamed the Ghost of Jupiter, this planetary nebula is bright enough to spot even under moderate light pollution. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

BY PHIL HARRINGTON

Phil is a longtime contributor to Astronomy *and the author of many books.*

This time of the year, the brighter constellations — like Leo, Ursa Major, and Boötes — tend to capture our attention to the north. Meanwhile, the sky's longest constellation stretches along our southern horizon, passing largely unnoticed. Hydra the Water Snake spans a full one-third of the sky, bridging the gap between the fading winter sky and the bright stars of the summer to come.

Hydra's brightest star, **Alphard** (Alpha [α] Hydrae), shines at 2nd magnitude, but none of the other stars that form its slinking figure break 3rd. This, coupled with its low altitude (for sky watchers in mid-northern latitudes), often means the Water Snake is devoured by horizon-hugging haze and light pollution.

But there are treasures hiding in Hydra that many amateurs ignore every spring. They are well worth the time and effort it takes to ferret them out, so let's give it a go.

There are treasures hiding in Hydra that many amateurs ignore every spring.

As you raise your binoculars toward Alphard, glance just 2° to its southwest for a lovely binary star. The 5th-magnitude primary is **27 Hydrae**, while its 7th-magnitude companion is listed as HD 80550 (SAO 136767). The pair is separated by about 4', making them easily resolvable. With 70mm and larger binoculars, 27 shows a subtle orangish hue for those with keen color perception.

Next, meander east from Alphard along the Water Snake's sinuous body as it slinks toward the dim constellations Sextans, Corvus, and Crater. Pause at 4th-magnitude Mu (μ) Hydrae. **NGC 3242**, spring's brightest planetary nebula, lies in the same field of view, 2° to Mu's south. William Herschel was first to lay eyes on it in February 1785. Its popular nickname, the Ghost of Jupiter, was derived from William H. Smyth's description in his classic 1844 observing guide, *A Cycle of Celestial Objects*. Although he didn't coin the term, Smyth wrote, "From its size, equable light, and color, this fine object resembles Jupiter; and whatever be its nature, must be of awfully enormous magnitude." Smyth was correct about its enormity: NGC 3242 measures about 2 light-years across its major axis. That's about 50 percent larger than the Ring Nebula (M57).

At 8th magnitude, NGC 3242 is bright enough to see through 50mm binoculars even under the veil of moderate light pollution. Like its namesake planet, the Ghost of Jupiter appears about 40" across. That means it will appear almost pinpoint at 7x to 10x magnification. But with a good chart of the area, you'll be able to pick it out. If you have keen color perception and 70mm or larger binoculars, you just might see a hint of its characteristic color. Some describe it as blue, while others say green.

Speaking of color, two of spring's most colorful carbon stars are also hiding in Hydra. Carbon stars appear especially red thanks to their carbon-rich atmospheres, which absorb shorter blue wavelengths of light. Just how red they appear will depend on how bright they are at the time, as they are variable stars. You can enhance their color by slightly defocusing your binoculars, but don't go more than one-eighth of a turn.

To find these two targets, hop east along the Serpent's body to Nu (ν) Hydrae. The first, **U Hydrae**, shines around 5th magnitude. Look for it about 4° northwest of Nu. It marks the south-pointing apex of a right triangle formed with two 6th-magnitude stars to its north. Studies show that U is about 3,400 times more luminous than our Sun and lies about 450 light-years away.

The other, **V Hydrae**, is found about 5° to Nu's south. This one will take a little more patience to hunt down because of its greater variability. It is typically around 6th to 7th magnitude, but can fade as low as 12th. So if you can't find it tonight, be sure to come back in the future and give it another try. At 2,000 light-years distant, V is much farther than U. It is also far more luminous: about 7,850 times greater than our Sun. V is actually a binary system, with a smaller companion star orbiting a red giant. Material is pulled from the red giant into a disk around the companion. When that material reaches a critical mass, about every eight years, it is ejected into space as blobs of hot plasma. Some astronomers suggest this process could portend a future planetary nebula. No doubt, V Hydrae is an exciting star to monitor and study.

Have a favorite binocular target? Let me know about it, so I can feature it in a future column. Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

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Your perfect first (and last) telescope

A bare-bones scope that fits most observer's needs.

Though buying your own 6-inch f/8 Dobsonian is usually the way to go, some observers choose to go the homemade route. JOSEPH DECHENE

BY GLENN CHAPLE

Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

When first glancing at that title, some experienced observers may think I've written myself into a corner. You see, there is no such thing as a perfect first telescope. In fact, there's really no such thing as a perfect scope, period. If you want to tease out the intricate details of Jupiter's cloud belts or split apart a tight double star, you'll need a scope that generates the highest practical magnification — perhaps a refractor or a catadioptric telescope (a type of telescope that combines both refracting and reflecting elements) with a high focal ratio, say f/10 or greater. However, if you want to chase "faint fuzzies," where the amount of light collected is paramount, you'd do well with a large-aperture reflector with an f/4 or f/5 focal ratio. So, unless you're content seeking out the same old targets over and over, the perfect (or near-perfect) scope should be a compromise.

The ability to reveal a wide spectrum of cosmic objects is just one requirement for an entry-level telescope. There are other, equally important, questions to consider before making your first purchase: Does it provide quality optics and mechanical stability at an affordable price? Is it lightweight and easily portable? Can it be set up without much time or fuss? Is it easy to use and maintain?

But if there is no "perfect" beginner's telescope, what should you choose to best satisfy all of the aforementioned criteria? I submit that it's a bare-bones 6-inch f/8 Newtonian Dobsonian-mounted reflector. An f/8 focal ratio permits high-power views of lunar and planetary detail and enough resolution to split double stars less than one arcsecond apart. Yet it still allows for satisfactory low-power, wide-field views of deep-space targets.

Although prices have risen in recent years, a typical no-frills, commercially made 6-inch f/8 reflector costs around $400 or less. Rarely heavier than 50 pounds (23 kilograms), these scopes are lightweight and portable, making them quick and easy to set up in your backyard or load into your car for a trip to a remote observing site. If it's perched on a simple Dobsonian mount (sans electronics), it can be ready to use in just a minute or two.

You might ask: Considering the availability of larger instruments, wouldn't you be short-changing yourself with a measly little 6-inch scope? Hardly! In a past column (April 2011), I sang the praises of my first astronomical telescope, Edmund Scientific's Space Conqueror, a 3-inch f/10 reflector. It was the only one I used during my first decade as an amateur astronomer, and I still take it out for the occasional spin around the galaxy. Over the years, that "little scope that could" has shown me innumerable lunar features; all of the planets (now that Pluto has been demoted); 120 asteroids down to magnitude 11.4; 1,500-plus double, triple, and multiple stars; more than 100 NGC objects; and the entire Messier catalog. It did serious citizen science work, too, helping me gather over 1,000 variable star estimates, which I forwarded to the American Association of Variable Star Observers. Now imagine what a backyard astronomer can do with a 6-inch reflector!

I submit that it's a bare-bones 6-inch f/8 Newtonian Dobsonian-mounted reflector.

Speaking of, here's an interesting thought for the seasoned backyard astronomer who needs to downscale from that bulky 12-inch Dob to something easier to handle. The same bare-bones 6-inch f/8 Dobsonian-mounted reflector telescope that's appropriate for the beginner will also satisfy your needs. Your last telescope won't have the light grasp of the big Dob, but you'll spend more time under the night sky — and your creaky back will thank you!

That brings me to the crux of this article: When asked to describe the perfect telescope for anyone, novice or expert, experienced skygazers will usually say the best scope is whichever one you'll use the most. And being versatile, relatively inexpensive, portable, and user-friendly, the classic 6-inch f/8 Dobsonian fits the bill perfectly.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Astroimaging for Dummies. Clear skies!

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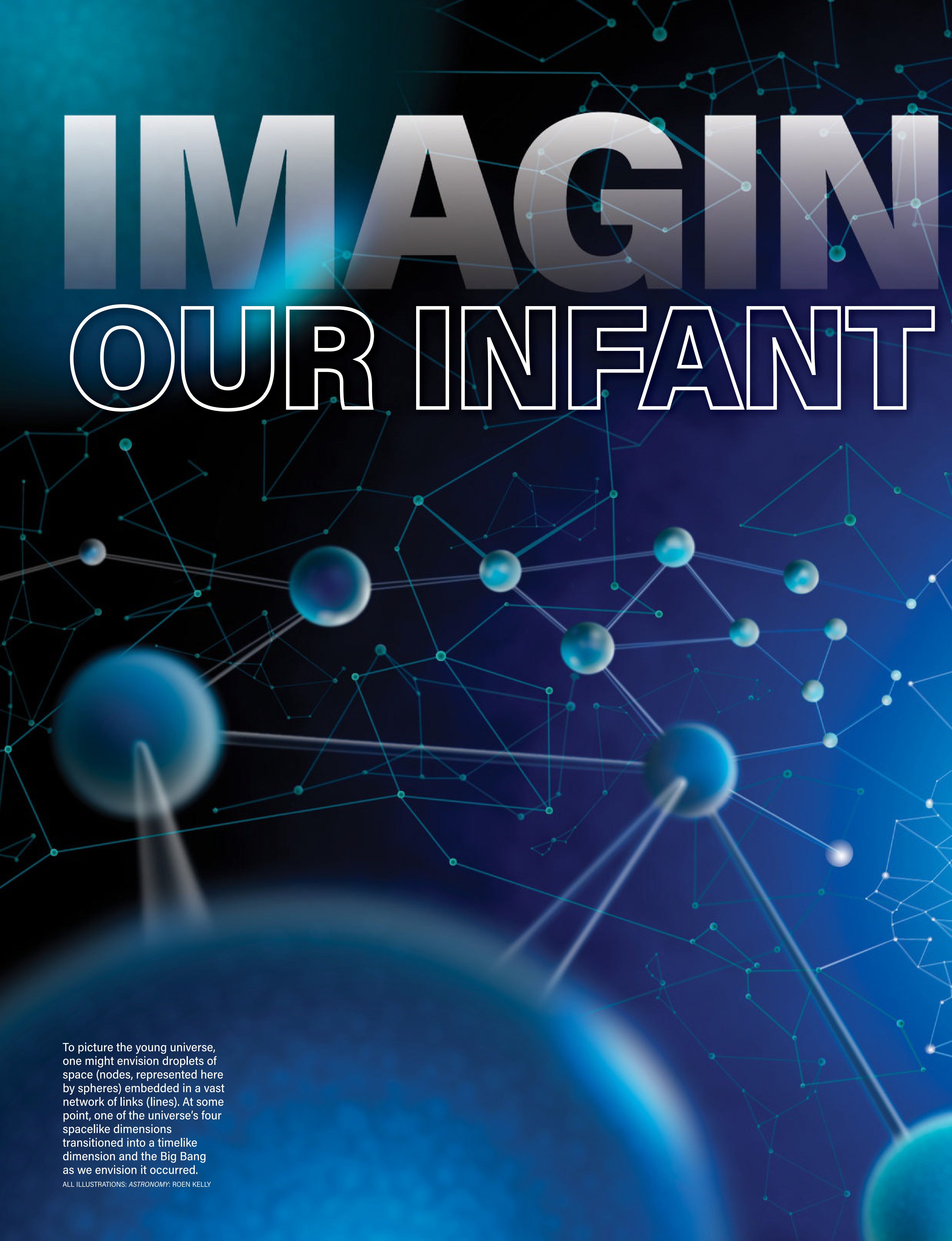
IMAGIN
OUR INFANT



To picture the young universe, one might envision droplets of space (nodes, represented here by spheres) embedded in a vast network of links (lines). At some point, one of the universe's four spacelike dimensions transitioned into a timelike dimension and the Big Bang as we envision it occurred.

ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

ING UNIVERSE

During the Planck era, the universe was so small that our laws of physics break down. To dive deeper back in time, we'll need new scientific language.

BY STEN ODENWALD

IN LESS TIME than it takes to snap your fingers, the universe flashed into existence.

Cosmogenesis is the breathtaking story of how this happened. It includes, in its later moments, the creation of the primordial elements and depicts their organization by dark matter and gravity into vast cosmic structures on the largest scales. Meanwhile, on smaller scales, local gravitational collapse created stars and, later, planets.

The prelude to this story began with a major cosmological event: inflation. Between 10^{-36} and 10^{-34} seconds after the Big Bang, the physical scale of our universe doubled in size more than 50 times, so that by today, it is trillions of times larger than the 14 billion-light-year extent we can observe.

Inflation's effects shaped the cosmos we see today: geometrically flat, homogeneous, and with the right mix of matter and energy. But what happened *before* inflation? The answer takes us deep into the nature of reality itself, and face to face with a time called the Planck era.

The GUT era

To probe the Planck era, we must first bridge an equally mysterious period called the GUT era.

The period of cosmic history before inflation kicked off, ranging from 10^{-43} to 10^{-36} seconds after the Big Bang, is almost unimaginable. But we think its properties are nevertheless calculable. During this time, gravity had become its own distinct force, but those forces we now experience individually as the separate strong, weak, and electromagnetic forces were all essentially indistinguishable.

There are many ways this unification could happen, each advocated as a separate theory. Collectively these are called Grand Unification Theories or GUTs. The simplest GUTs propose the existence of families of supermassive particles of 10^{14} gigaelectronvolts (GeV) or more. They are partners to our familiar Standard Model particles, which have masses from 0 to about 150 GeV.

The temperature and density of the cosmos during the GUT era was unimaginably gargantuan: 10^{28} kelvins and 10^{80} grams per cubic centimeter. (For comparison, a neutron star has a density of about 10^{15} g/cm^3.) Typical distances between particles were 10^{-26} cm or less. What's more, particles simply popped in and out of existence in matter-antimatter pairs from out of their respective quantum fields. At this energy scale, where typical particle energies were above 10^{15} GeV — namely, those of the supermassive GUT particles — the familiar Standard Model particles were essentially massless by comparison. They behaved more like photons.

The comings and goings of the supermassive GUT particles tossed the gravitational field of the universe about like waves on a stormy sea. Space and time themselves were warped by the many sudden changes in this turbulent gravitational field.

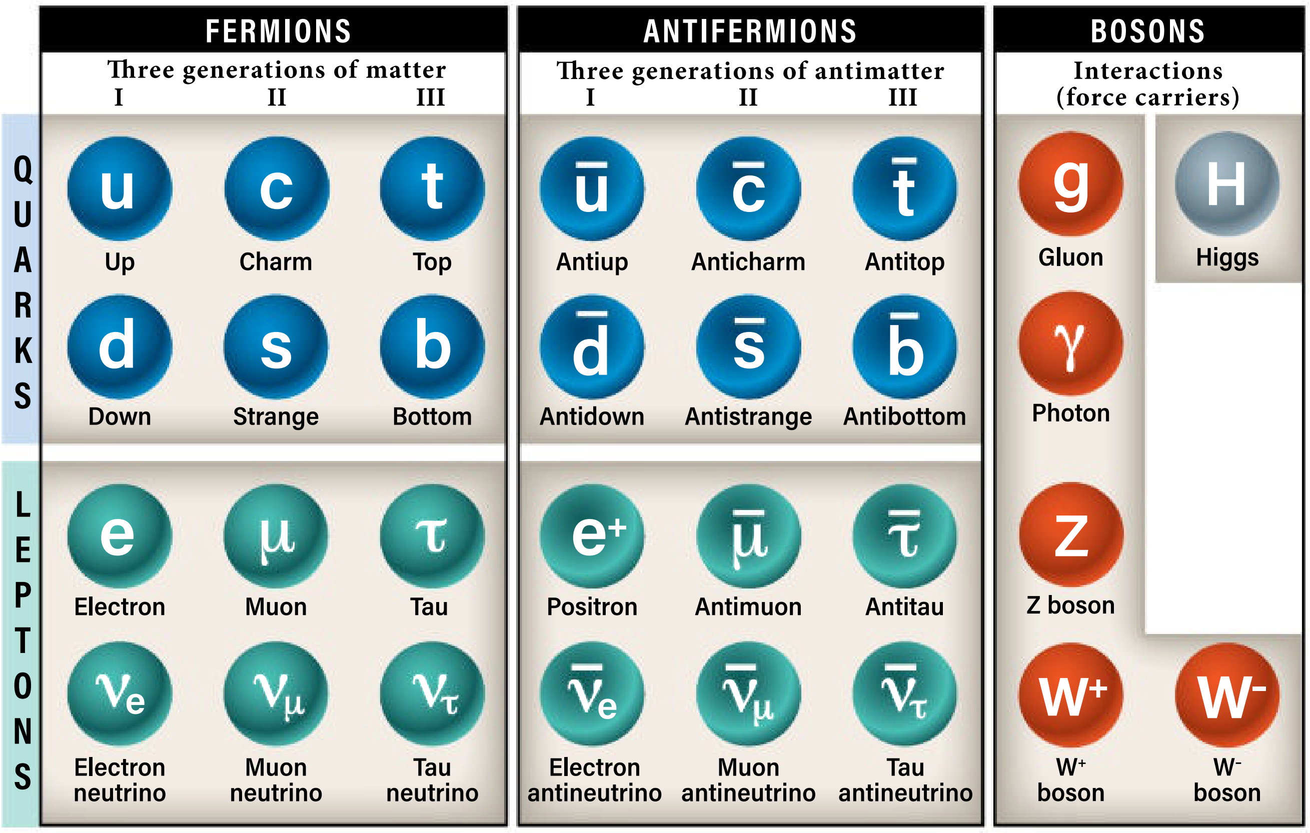
The GUT era was indeed an incomprehensible, fluctuating, hot mess of interacting particles and fields. Physicists

THE STANDARD MODEL

CURRENTLY, OUR BEST THEORY to describe the way matter in our universe behaves is called the Standard Model.

The Standard Model consists of one family of particles called fermions and one called bosons. Within the matter-generating fermion family of 12 particles, there are three generations of particles: I, II, III, along with their antimatter counterparts. Within the similar 12-member family of force-producing bosons are the photon (responsible for electromagnetism), eight gluons (carrying the strong nuclear force), and three W and Z particles (creating the weak nuclear force). There is also the Higgs boson, which is responsible both for giving all the Standard Model particles (minus photons and gluons) mass and for making the weak and electromagnetic forces behave differently.

The simplest GUT model, called Minimal SU(5), adds a collection of supermassive fermions. It also adds 12 force-carrying bosons. These new bosons include the supermassive X and Y leptoquark, which can, through interactions, turn leptons into quarks and vice versa. There are also 25 new supermassive Higgs bosons to cause the strong force and the electroweak force to behave differently. *— S.O.*

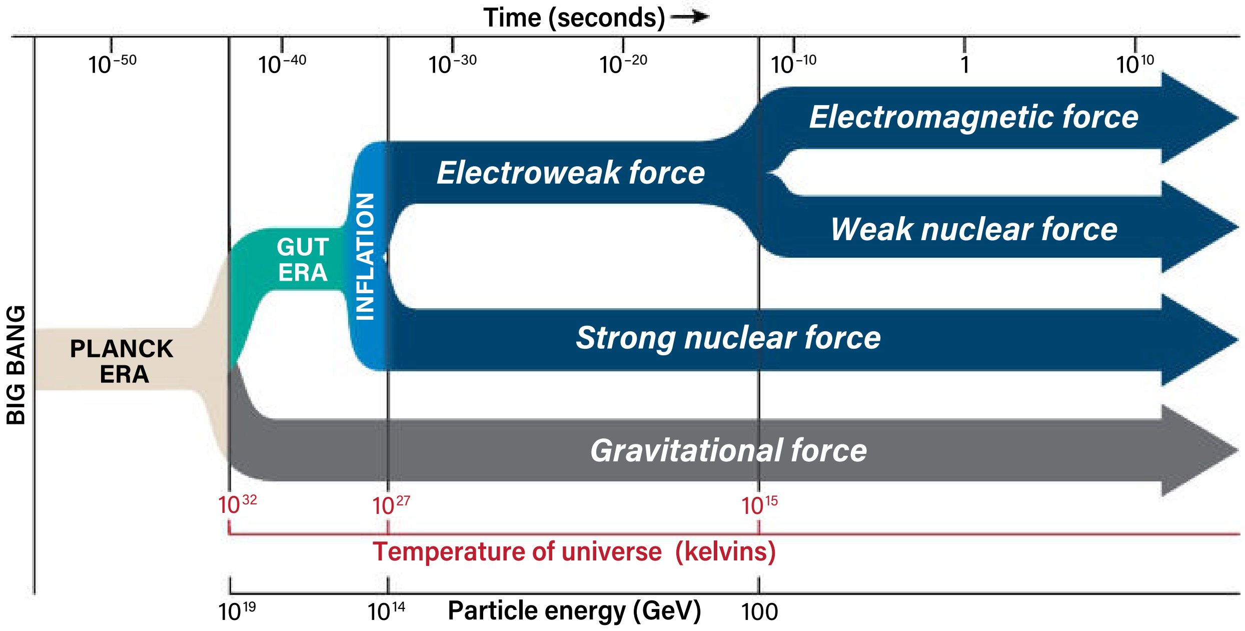


	FERMIONS Three generations of matter			ANTIFERMIONS Three generations of antimatter			BOSONS Interactions (force carriers)	
	I	II	III	I	II	III		
QUARKS	u Up	c Charm	t Top	$\bar{u}$ Antiup	$\bar{c}$ Anticharm	$\bar{t}$ Antitop	g Gluon	H Higgs
	d Down	s Strange	b Bottom	$\bar{d}$ Antidown	$\bar{s}$ Antistrange	$\bar{b}$ Antibottom	γ Photon	
LEPTONS	e Electron	μ Muon	τ Tau	e^+ Positron	$\bar{\mu}$ Antimuon	$\bar{\tau}$ Antitau	Z Z boson	
	ν_e Electron neutrino	ν_μ Muon neutrino	ν_τ Tau neutrino	$\bar{\nu}_e$ Electron antineutrino	$\bar{\nu}_\mu$ Muon antineutrino	$\bar{\nu}_\tau$ Tau antineutrino	W^+ W^+ boson	W^- W^- boson

This table shows the particles of the Standard Model, which include matter-generating fermions and their antimatter counterparts, as well as force-generating bosons. GUTs add supermassive particles, which become most important in the early universe, to this mix.

believe these messy conditions continued all the way down to a scale of 10^{-33} cm and time intervals of 10^{-43} seconds, called the Planck size and time. The Planck scale, whether referring to size, time, mass, or otherwise, is the smallest unit of the universe we can describe — or, perhaps, that even exists. Below these scales, our current theories about space and time completely break down. If we try to describe the universe at a time *before* 10^{-43} seconds in its history — the Planck era — we discover that both time and space lose their conventional meaning.

THE FOUR FUNDAMENTAL FORCES



Today, four fundamental forces exist: the strong nuclear force, the weak nuclear force, the electromagnetic force, and the gravitational force. According to unified theories, early in the universe's existence these forces began as a single force, with each separating out at a specific temperature as the cosmos cooled.

The nature of time and space

The reason our descriptions of time and space break down near the Planck era is that the gravitational field at this time was so distorted and turbulent with its own quantum fluctuations, it is impossible to define a clock to measure time or a ruler to measure length. Only a fully quantum mechanical description of gravity — which we don't yet have — will let us probe deeper into this corner of cosmic history.

If we *could* examine physics at the Planck scale today, we would see what this quantum chaos is like. But at this scale, nature defeats our best efforts to observe it at all.

If you try to study the gravitational field of the cosmos down to 10^{-33} cm using a photon, its energy would have to be so high (10^{19} GeV) that it would immediately (after 10^{-43} seconds, the Planck time) become a tiny, quantum black hole with the smallest possible mass and event horizon radius: 10^{-5} gm and 10^{-33} cm (the Planck mass and size). The black hole would then evaporate and destroy the very information you were trying to extract.

Since the 1930s, physicists have preferred to think of gravity and the way it acts on matter and energy as simply another name for space-time. In Einstein's theory of general relativity, space-time in the guise of the gravitational field provides the coordinates in space and time (x, y, z, t) that quantum mechanics needs to describe all the other fields corresponding to the Standard Model particles. General relativity provides what physicists call a background-independent way to define space and time as a collection of fundamental events and the relationships between them.

Quantum mechanics, on the other hand, requires the pre-existence of these coordinates to define fields, which means it is a background-dependent theory. To make general relativity and quantum mechanics play together, quantum mechanics must be rebuilt in terms of coordinates defined only by the gravitational field.

Despite a century of effort, physicists still do not have such a quantum theory for gravity that reproduces our universe at both quantum and cosmic scales. What's more, not a single observation suggests that gravity *has to* be quantized at all. Richard Feynman once noted: "The extreme weakness of quantum gravitational effects now poses some philosophical problems: maybe nature is trying to tell us something new here, maybe we should not try to quantize gravity."

But that doesn't stop physicists from trying to do it!

Quantizing gravity

Treating gravity as just another quantum field like the ones in the Standard Model would complete our description of the physical world as a set of interacting quantum fields. Most physicists consider such a theory the epitome of beauty and elegance. Quantum gravity theory currently takes two popular, complementary forms: superstring theory (also simply called string theory) and loop quantum gravity.

In string theory, Standard Model particles are represented as one-dimensional strings of energy that move and vibrate within an 11-dimensional arena called the Bulk. Strings can either be open with two ends, like a piece of spaghetti, or closed like a rubber band. Different vibrations of these strings in seven compact dimensions represent each type of particle in the Standard Model.

Open strings are anchored

at each end on three-dimensional objects called branes. Confined within just one of these branes — the one that comprises our particular universe — are all the Standard Model particles and hopefully a few more, such as those we suspect are responsible for dark matter, dark energy, and inflation. Closed strings, meanwhile, represent gravitons, which are the fundamental particles, or quanta, of the gravitational field. These are free to move across all dimensions of the Bulk.

A three-dimensional brane represents one possible state of 3D space at a specific instant — a snapshot of the universe. As time ticks by, it generates a collection of branes, like the successive pages in a book, that represent our entire four-dimensional universe.

But like current quantum theory, string theory relies on the pre-existence of space-time and does not (as yet) provide insight into gravity as a quantum field. Strings provide no clues to how to interpret the space-time they are embedded within. Instead, space-time is the passive coordinate framework within which strings move. What's more, string theory requires up to seven additional dimensions with complex, spacelike geometries, but at imperceptible scales of 10^{-33} cm.

Even though this theory has room in it for gravity-carrying particles, these only weakly interact with the background space-time. To be a full quantum theory of gravity, string theory would also have to create the space-time background within which it operates. Thus far, it cannot. For that, we must entertain another theory.

Loop quantum gravity (LQG) offers a way to break down space and time into their smallest possible pieces. In LQG, the basic ingredient of space is called a node. It is the size of the Planck volume: $(10^{-33}\text{ cm})^3$. Nodes are the only physically detectable elementary ingredients of space and provide the coordinate network for space-time. They are connected to each other by links, but these do not physically exist in space or time. Links are assigned integer numbers (their spins) that relate to the quantized area they represent in multiples of the Planck area $(10^{-33}\text{ cm})^2$. And a collection of links and nodes at any given instant is called a spin network. For example, the volume of a single atom of hydrogen $(10^{-8}\text{ cm})^3$ consists of a spin network described by 10^{75} nodes.

Each spin network represents a state of 3D space at a particular time: a possible way in which space can be quantized. You can imagine that space looks like a lattice constructed from Tinkertoys, but in which only the round spools (nodes) can be seen. The rods (links) connecting the spools are hidden, but still essential in creating the lattice. In the same way that you can add and remove rods in your Tinkertoy lattice, spin networks can change through a specific set of cause-and-effect moves by changing the links at each node. This sequence of moves forms what is called a spin foam.

Imagine taking a movie of your Tinkertoys in which each frame shows the lattice after making a single change. The movie (or spin foam) encodes the sequence of moves and changes along a fourth dimension — we interpret this dimension of change as time. And the time step between successive frames represents one Planck time (10^{-43} seconds). But what we call "time" is just the way in which the 3D spin networks are stacked along a fourth

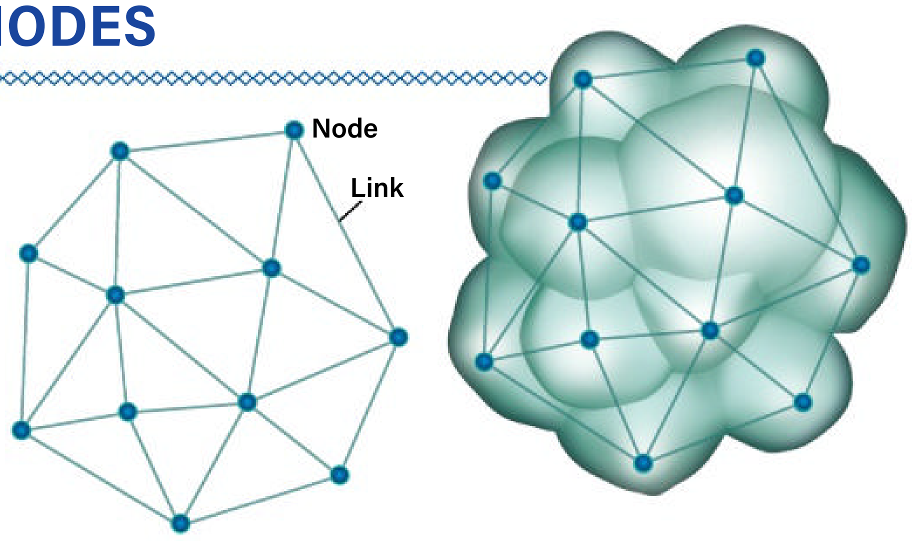
QUANTUM FIELDS

PHYSICISTS HAVE DEVELOPED a detailed mathematical picture of matter and forces in terms of a concept called the quantum field. A quantum field consists of innumerable quanta (small packets) of energy, called virtual particles, that are emitted and absorbed by matter particles such as electrons and quarks. We interpret this exchange as a force acting between the particles.

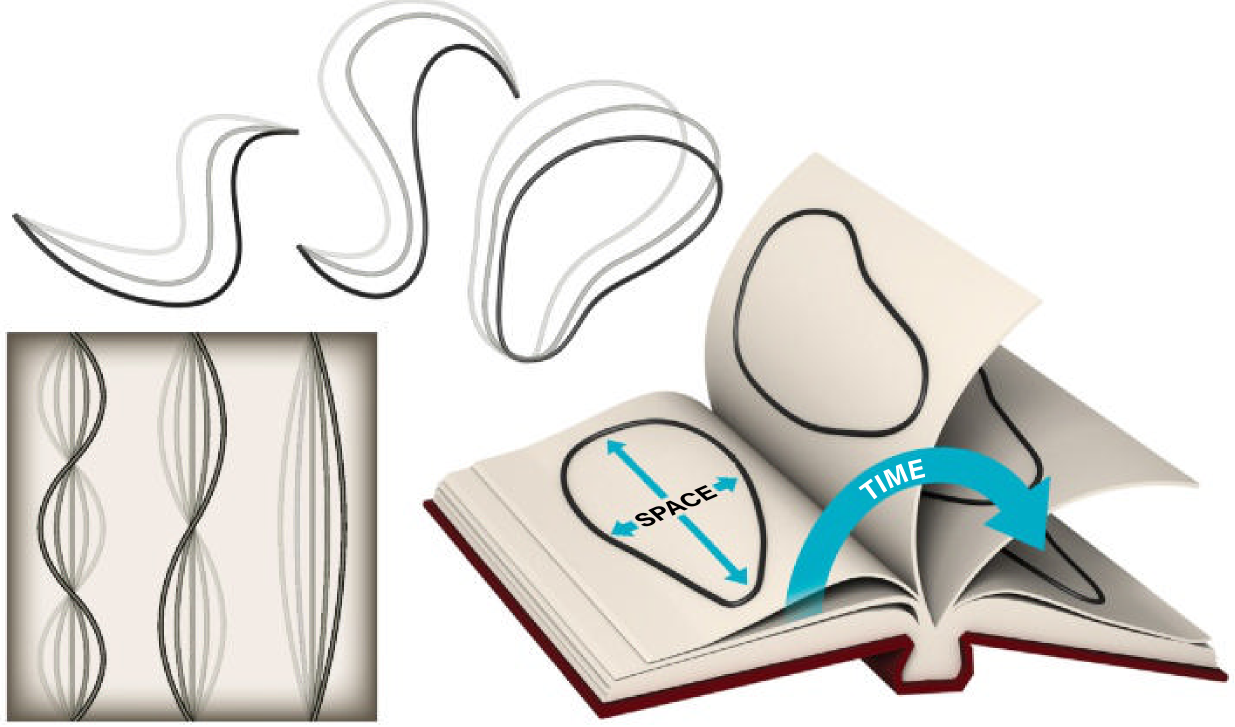
In fact, the matter particles themselves are seen as persistent excitations in their respective quantum fields — one for each kind of Standard Model particle. An important ingredient of quantum fields is that, thanks to Heisenberg's uncertainty principle, particles can appear and disappear literally from out of nothingness, usually called the vacuum state. Researchers have experimentally confirmed this in many different ways since the 1940s. By adding enough energy to a collision between physical particles, we can promote these virtual particles into real particles, but only in matter-antimatter pairs. This is how the Large Hadron Collider creates many other particles as debris from the energy of proton-proton collisions. *—S.O.*

LINKS AND NODES

A small portion of a spin network (left) shows nodes (blue dots) and links (lines). At right, the same network appears with the surface areas of the nodes, visible as shaded regions. The network specifies how many neighbors a node can have and forms the basis for defining geometry.



PICTURING STRING THEORY



LEFT: In string theory, elementary particles are not points but vibrating strings. Each particle type is determined by the frequency of the vibration. Strings may be open-ended or closed loops.

RIGHT: Strings are anchored on three-dimensional branes. Each brane represents our universe at a specific instant, like the page of a book. As time progresses, it generates successive branes, like turning the pages of the book.

dimension as each change takes place. And spin foams are quantum states of four-dimensional space-time.

The Planck era

We now have two different but related dictionaries for how to describe what is going on at the Planck scale: string theory and LQG. And this means we now have a way to describe the conditions in the universe during and just after the Planck era. Here is one story of what the Planck era might have looked like and what it might tell us about cosmogenesis, told in the combined language of string theory and LQG.

The Nothing State: In many ways, the "beginning" of the Planck era is not a logical concept. Nor does it have an actual name, because any name presupposes a time, place, or quality, none of which may apply here. According to physicist Daniele Oriti at the Max Planck Institute for Gravitational Physics in Potsdam, Germany, this primitive Nothing State may have consisted of ingredients that were not spacelike or timelike at all.

But as Nobel laureate and physicist Frank Wilczek once said, "The reason that there is Something rather than Nothing is that Nothing is unstable." This instability led to a phase change in the Nothing State. In the language of LQG, Nothingness was converted into Something: a plenum of innumerable elemental Planck volume nodes. This occurred in perhaps the same way that a cloud of water molecules in a gas changes phase into a cloud of liquid droplets — rain — when the temperature falls.

Geometrogenesis: Our new Something State, consisting of droplets of space (nodes), did not remain random for long. The nodes were embedded in networks of links that defined the spin network's dimensionality (N), which in turn defined the number of nearest neighbors to each node. According to Lee Smolin — one of the developers of LQG — of the Perimeter Institute for Theoretical Physics in Waterloo, Ontario, the available energy to maintain these links may have been so enormous that the Planck volumes could have been elements of a space with vastly more than the supposed 11 dimensions of the Bulk. But even this state was unstable and spawned a second phase change as the available energy declined.

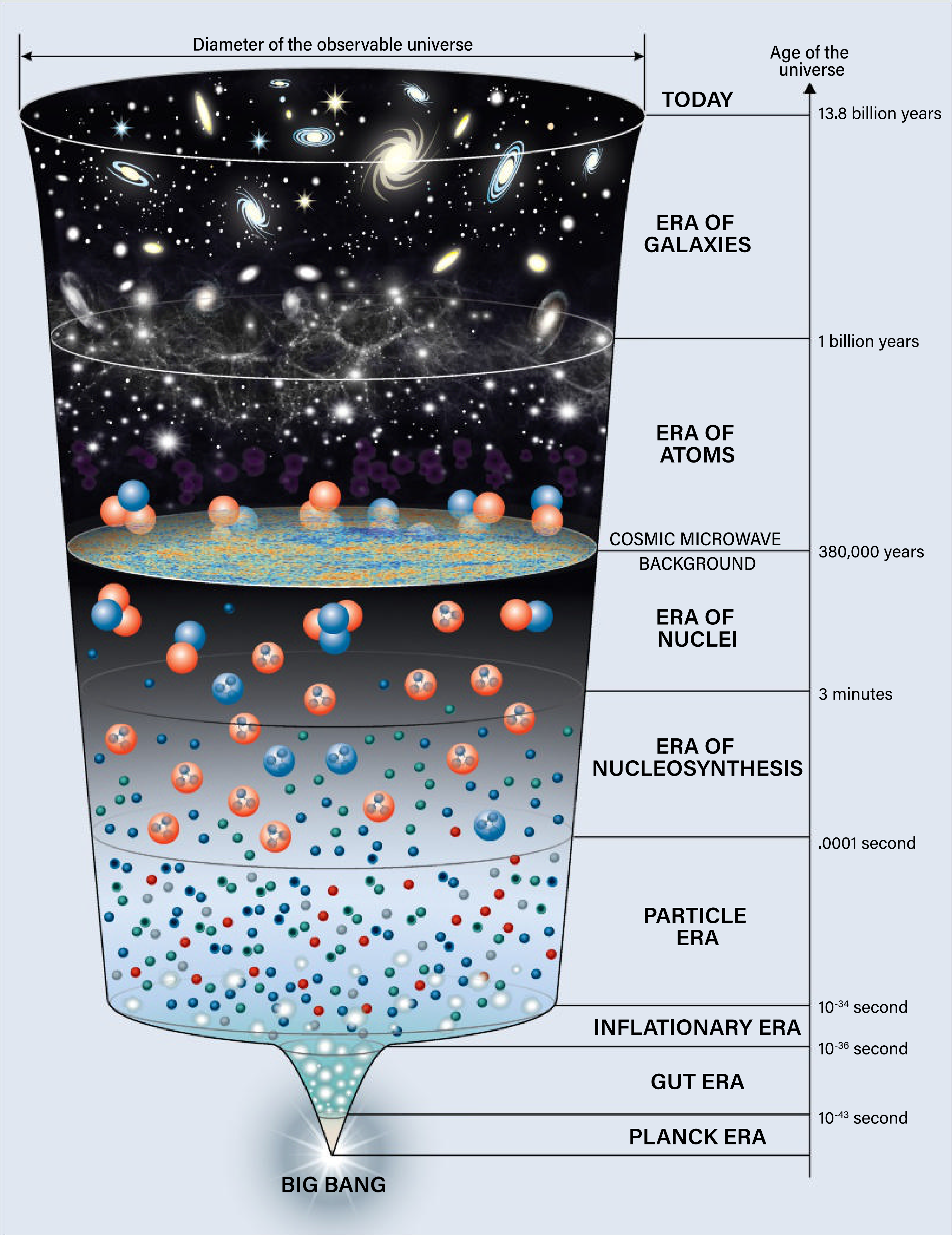
Imagine a very peculiar landscape. There are mountains where links are numerous (large numbers of dimensions). These locations require huge amounts of energy to maintain themselves. And there are valleys (with fewer dimensions), where less energy is required. Phase changes occur when it is more favorable for a system to exist at a lower energy that at a higher one. This suggests that spaces with huge numbers of dimensions tend to become spaces with lower energy and fewer dimensions. The change happens by way of a process called quantum tunneling.

So, we can imagine a second phase change occurred when the new N-dimensional Something State tunneled to one of these lower-energy states of spin networks with fewer links between nodes. All but 11 of the originally numerous dimensions disconnected from the nodes and vanished. This may have formed the geometric basis for the Bulk in string theory.

Compactification: According to string theory, there must have been some event, process, or circumstance in which seven of the 11 dimensions of the Bulk were compactified to create the specific details of the Standard Model in our four-dimensional universe. We can imagine this as a third phase transition that, in the language of LQG, caused the links representing seven of the 11 dimensions to develop closed spaces, each with a specific geometry. Among the remaining four dimensions, three formed three-dimensional spacelike spin networks, or branes.

Chronogenesis: A fourth phase transition occurred as one of the four spacelike dimensions in the Bulk tunneled into a timelike dimension that tracked the changes taking place between configurations of spin

A COSMIC TIMELINE


Diameter of the observable universe
Age of the universe
TODAY
13.8 billion years
ERA OF GALAXIES
1 billion years
ERA OF ATOMS
COSMIC MICROWAVE BACKGROUND
380,000 years
ERA OF NUCLEI
3 minutes
ERA OF NUCLEOSYNTHESIS
.0001 second
PARTICLE ERA
10^{-34} second
INFLATIONARY ERA
10^{-36} second
GUT ERA
10^{-43} second
PLANCK ERA
BIG BANG

networks to produce spin foams. Stephen Hawking and James Hartle proposed this idea in 1983 to solve the problem of the origin of time in cosmology. They called it the no-boundary proposal because it eliminated the need for discussing what happened *before* the Big Bang. Essentially, they said, the universe has no boundary (beginning), just as there is no point north of the North Pole. Once one dimension emerged as the direction of a succession of spatial states (branes in string theory; spin networks in LQG), it established cause and effect, and the Big Bang occurred.

Cosmogenesis: At first, the scope of the Big Bang was limited to the Planck scale as bubbles of new space-time emerged from within the vaster network of purely spacelike dimensions. This was an unimaginably turbulent time, perhaps resembling the topsy-turvy chaos of what theoretical physicist John Wheeler called quantum space-time foam. Collections of nodes came together to form the first primordial objects — quantum black holes — but these quickly disintegrated back into individual nodes. Other collections of nodes took on wavelike behavior and traveled through the spin foam network as gravitons.

Structures larger than the Planck scale began to form stringlike objects consisting of nodes organized along one dimension of space. With the information (provided by their links) about the seven compact dimensions, they took on the properties of the individual particles we recognize in the Standard Model. Huge ensembles of these strings began to behave as organized quantum fields. The way in which one string interacted with another is described by the way in which one enormous collection of nodes changed into another collection as part of a spin foam pattern.

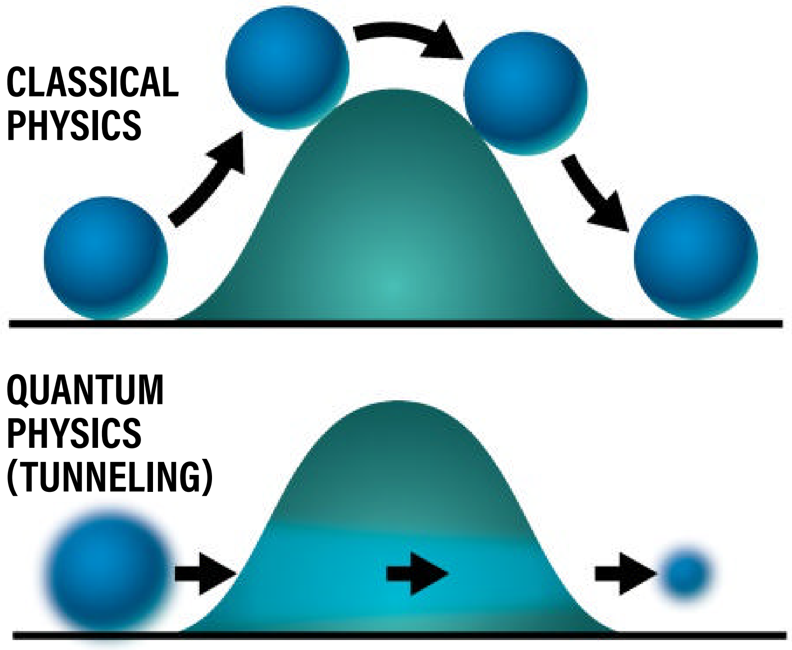
During all these phase transitions, the amount of information coded into the network of nodes steadily increased. This had a profound effect upon how precisely the mathematical relationships between nodes along the emerging time axis could be specified. These relationships are what we call the physical laws of nature and include how we describe gravity and the details of the Standard Model. So, during this later stage of the Planck era, not only did time emerge, but also the laws of nature now operating across our space-time.

In his book *The Mind of God*, Paul Davies notes that "[Prior to] one second after the Big Bang there was less space and less information, so mathematics was in a cruder form. The computing power of the universe near the Planck time was essentially zero. All math would have been meaningless, and laws would have been nearly impossible to state."

At first, the physical laws were very approximately specified, but as time passed and the available information grew, these patterns became more detailed. In essence, the physical laws of our universe emerged from the growing information content of the universe within which these laws could be defined. Once these patterns emerged and became more precise, the progression of the Big Bang became richer in specific patterns for how particles interact across space and time.

QUANTUM TUNNELING

QUANTUM TUNNELING is the ability for atomic systems to change from one energy to another in a way that seems to violate the conservation of energy. In Newton's physics, an energy barrier can prevent a system from changing states. In quantum mechanics, Heisenberg's uncertainty principle does not allow a state's energy to be specified with perfect accuracy, so it may possess enough energy to overcome the barrier and change. This change is quantum tunneling; it is why some elements are radioactive and why fusion happens in the Sun. Tunneling can also transform an otherwise stable system at its minimum energy into one of slightly lower energy — this is what happened during geometrogenesis. *— S.O.*



Quantum tunneling allows a system to undergo a change in energy that seemingly violates Newtonian conservation of energy. This is possible because in quantum mechanics, the true energy of a system can never be precisely known, so it may have the energy required to change states through tunneling.

The bigger picture

If we were to step back and look at the big picture during the Planck era, we might envision a succession of bubbles within bubbles. The largest of these encompasses the domain of the spin networks in which other numbers of dimensions exist. Within some of these bubbles, space crystallized into 11 dimensions. We call our 11-dimensional bubble the Bulk. But there may be other Bulks with fewer or more than 11 dimensions.

Furthermore, within our Bulk bubble, one of the dimensions transitioned into time and served to organize the 3D branes (spin networks) into a recognizable, chronological order: our 4D space-time. Another transition compactified seven of the spacelike dimensions, bringing into existence our specific Standard Model particles and fields. Only the exact geometry of the compact 7D spaces defines what the Standard Model will look like for any given universe. But because string theory provides 10^{500} ways to do this, there are many different 11-dimensional Bulks, each with its own way of compactifying those seven dimensions.

Taken together, these are called the Landscape. You may know it as the idea of a multiverse. Continuing the analogy of our universe as a 4D collection of branes like a book, then the Bulk is like a giant library containing an infinite number of these book universes, each with different geometries for these compact spaces, leading to different Standard Models.

Back in our own space-time bubble, now vastly larger than the Planck scale, the background network of nodes defining the spin foam in four dimensions began to look smoother and smoother at larger scales as the universe became older. After a period of time, inflation occurred, ending some 10^{-34} seconds after the Big Bang ... and here we are!

Of course, this entire story is highly speculative, even fanciful. It is based on theories or pieces of theories that remain largely unproven — or perhaps, one shudders to think, even unprovable. But our quest for the origin of the universe is a result of who we are as sentient beings.

Put together with observations, we can continue to create and improve origin stories of the universe that answer many older questions while offering new ones for future generations to explore and test.

Sten Odenwald *is an infrared astronomer who worked on the Cosmic Background Explorer. He religiously keeps up with early universe theory.*

THE PLANCK SCALE

THE PLANCK SCALE defines the smallest unit of the universe — be it time, size, mass, etc. — that it is possible to describe. These values are determined only by the constants that define our universe. At sizes smaller than the Planck scale, our understanding of physics breaks down. Here are the currently most-accurate values of the Planck scales mentioned in this story, according to the National Institute of Standards and Technology, provided in SI units:

Length: 1.616255 x 10^{-33} cm

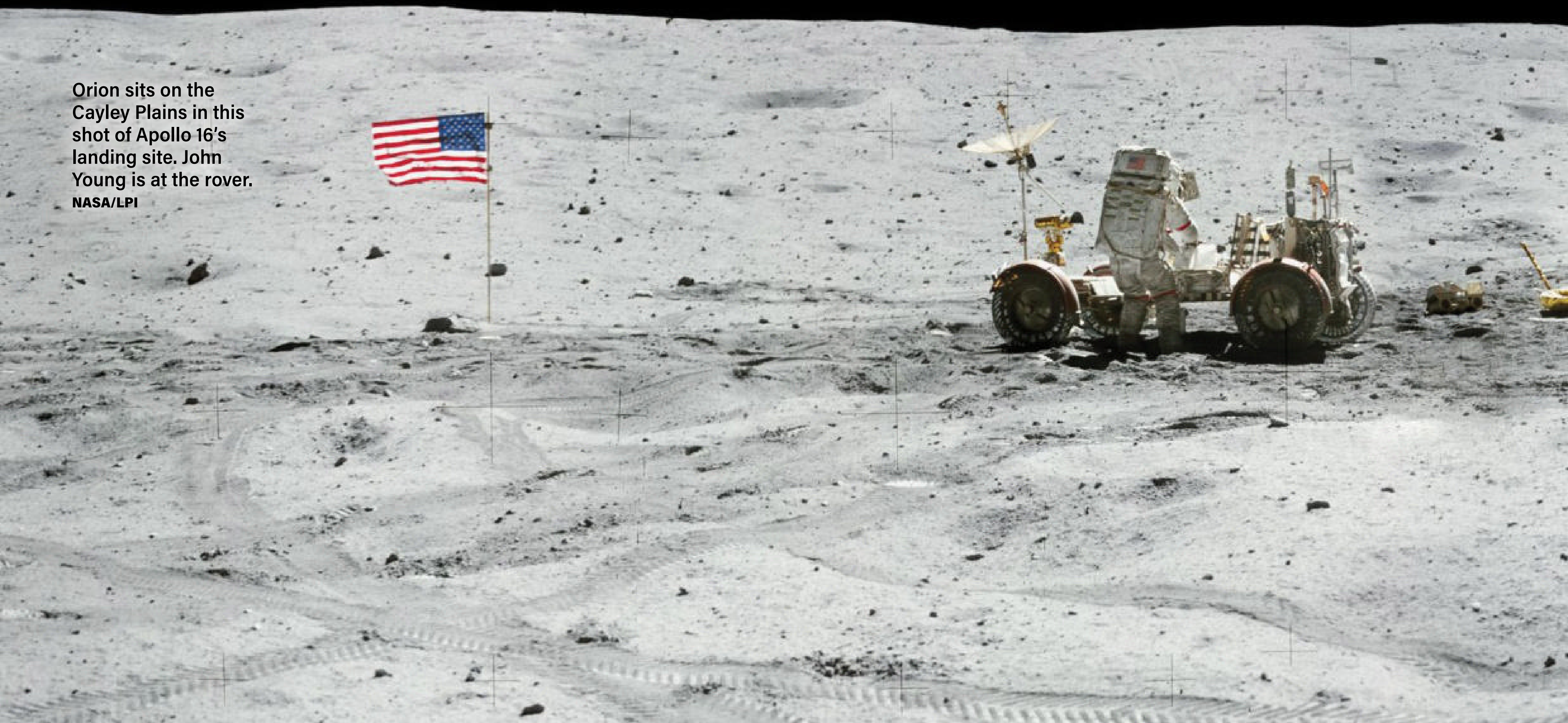
Mass: 2.176434 x 10^{-5} g

Time: 5.391247 x 10^{-44} s

50 YEARS AGO

APOLLO roves the lunar

The fifth crew to land on the Moon took lunar geology to new heights. BY MARK ZASTROW



Orion sits on the Cayley Plains in this shot of Apollo 16's landing site. John Young is at the rover.
NASA/LPI

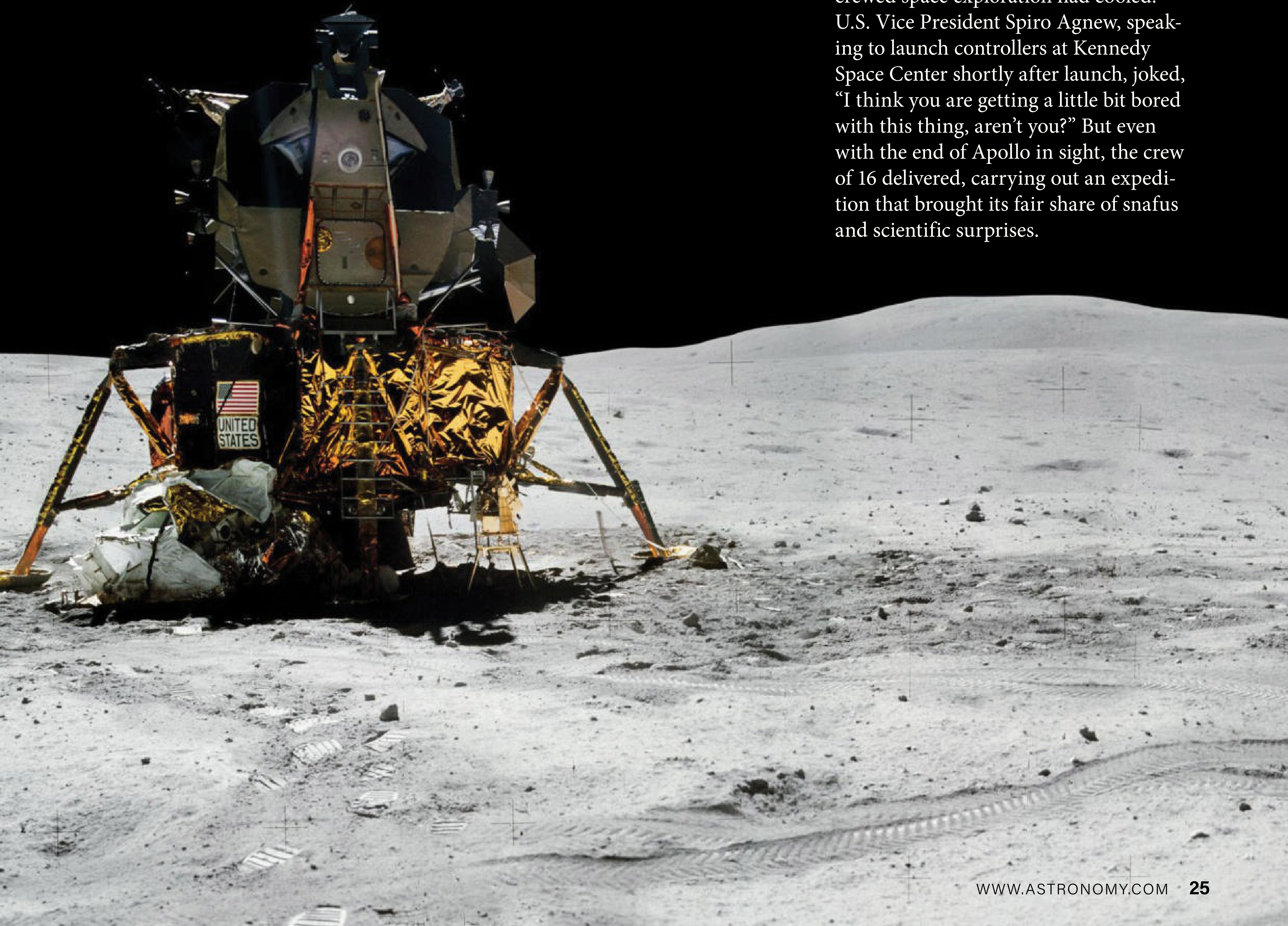
16 highlands

BY THE SPRING OF 1972, traveling to the Moon was, if not routine, at least a more confident affair. When Apollo 16 astronauts John Young and Charlie Duke stepped off the ladder of the Lunar Module (LM) *Orion* onto the lunar surface, “there wasn’t any tentative step,” Duke later said. “It was just: Jump off and start work.”

When Duke and Young hit the regolith, it marked the first time that astronauts had set foot in the rugged lunar highlands. Apollo 16’s landing site was Descartes, a region some 7,400 feet (2,250 meters) higher than the Sea of Tranquillity, where Apollo 11 had touched down. Researchers believed the Descartes hills had been formed by lava flows and would yield volcanic material — like igneous rocks — older than the maria where Apollos 11 and 12 had landed.

For the laconic Young, the mission’s commander, it was the second trip to the Moon, having orbited it as the Command Module Pilot (CMP) on Apollo 10. He was also a veteran of the Gemini program, having flown on Gemini 3 and commanded Gemini 10. Duke, the mission’s Lunar Module Pilot, was an enthusiastic rookie; Apollo 16 would be his first and only spaceflight. Ken Mattingly had been slated to fly as CMP on Apollo 13 but was grounded after being exposed to the measles and shifted to Apollo 16.

All the while, uncertainty hung over the future of NASA. Political support for crewed space exploration had cooled. U.S. Vice President Spiro Agnew, speaking to launch controllers at Kennedy Space Center shortly after launch, joked, “I think you are getting a little bit bored with this thing, aren’t you?” But even with the end of Apollo in sight, the crew of 16 delivered, carrying out an expedition that brought its fair share of snafus and scientific surprises.



* * *

Apollo 16 got off to an inauspicious start, with a string of minor glitches. Paint was flaking off the LM's insulation for no apparent reason. The crew discovered a software bug that crashed the guidance system. Upon arriving at the Moon, the LM's communications antenna jammed and its landing radar malfunctioned. Charlie Duke had issues zipping up his spacesuit. And when he finally did, his mic was positioned awkwardly: It tended to bump into his drink tube, spraying the inside of his helmet with an orange-flavored sports drink. (The liquid was laced with potassium to ward off irregular heartbeats that had affected some previous Apollo astronauts.) So, when Young and Duke finally climbed into Orion *and separated from the Command Module (CM)* Casper, *spirits were high. It seemed the mission was back on track.*

YOUNG (TO CM): Boy, Ken, you look great!

MATTINGLY (TO LM): Well —

DUKE (TO CM): You really got a pretty spacecraft!

MATTINGLY (TO LM): Yours is a *[garbled]* pretty one, too.

JIM IRWIN, CAPSULE COMMUNICATOR (CAPCOM): *Orion*, this is Houston. How do you read?

DUKE: Roger. You're five by [five], Jim, and we're sailing free. *[Pause.]* OK, Jim. It was a little rushed, but we got it done. The only bad thing is, I got a hat full of orange juice.

The two craft were in an elliptical orbit that dipped to just 11 miles (18 kilometers) above the lunar surface near the landing site. While on the farside of the Moon and out of contact with Houston, Mattingly in the CM would raise Casper's *orbit using the Service Module's main engine. It was less than an hour before Young and Duke would begin their descent.*

DUKE (ONBOARD LM): Here we go.

YOUNG (ONBOARD LM): Now, shall we do it?

DUKE (ONBOARD LM): Oh …

YOUNG (ONBOARD LM): Might as well. […]

YOUNG: Ken, do you read us on VHF [Very High Frequency radio]? Over.

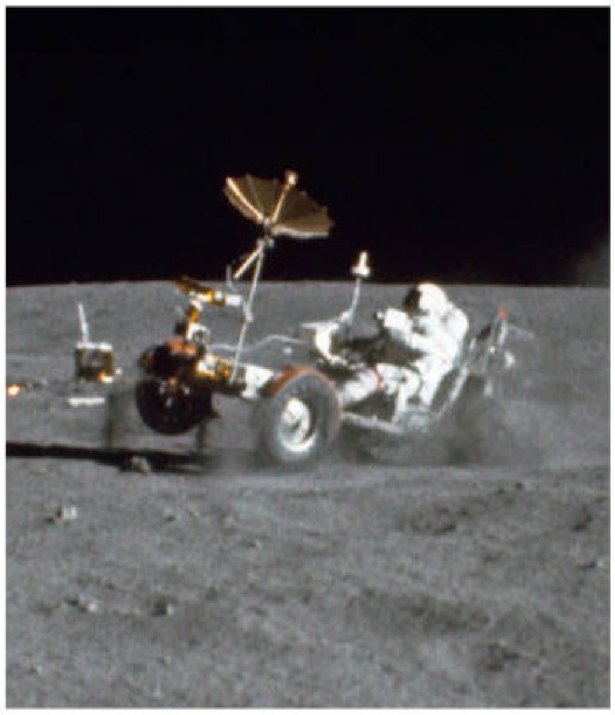
MATTINGLY: Yes, loud and clear.

YOUNG: You fixing to do the burn, right?

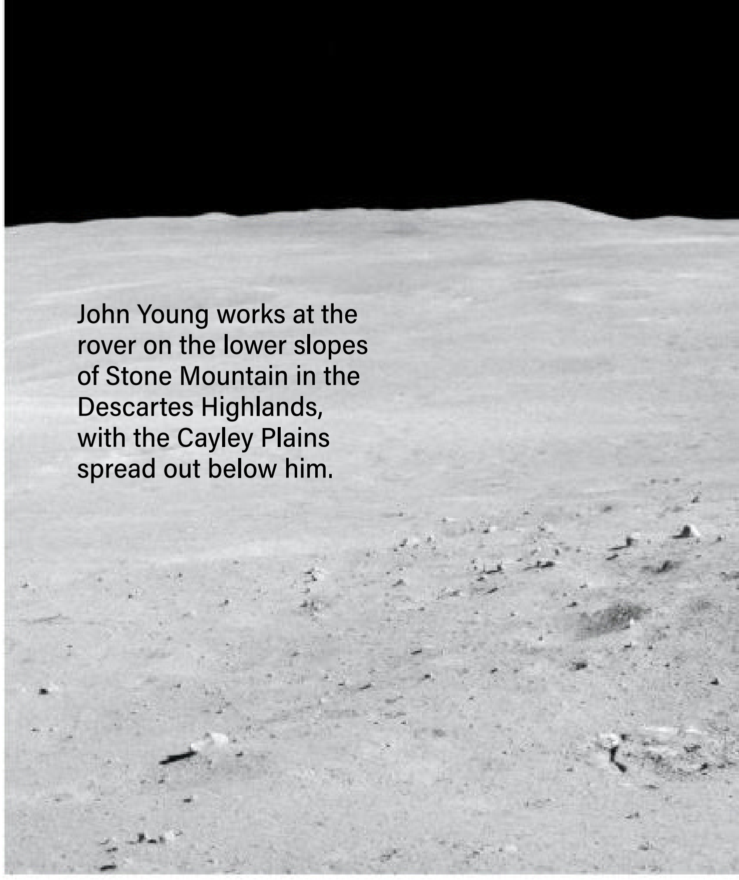
MATTINGLY: Sure am.

It was then that Apollo 16's most serious problem hit: Before the circularization burn, Mattingly had to run an automated test of all four of the Service Module's engine gimbals, two in the primary system and two in the backup system. These gimbals swiveled the engine to steer its direction of thrust. Mattingly recalled the test in a 2001 NASA oral history: "So you start the little computer program, and it just automatically swings the gimbal up, swings it down, left, right, puts it back in the center, switches over to the other [backup] system, and does the same thing, and you just watch it. It's a little thing that you do, kind of a ritual, happens about 20 seconds before the burn."

Apollo 16 lifted off from Launch Complex 39A at the Kennedy Space Center at 12:55 P.M. EST on April 16, 1972. NASA/KIPP TEAGUE



At the end of the first EVA, Young put the rover through its paces in a test drive dubbed the "Grand Prix," which Duke filmed on a 16mm camera. He enthusiastically reported to Houston: "He's got about two wheels on the ground. There's a big rooster tail out of all four wheels. And as he turns, he skids. The back end breaks loose, just like on snow. […] Man, I'll tell you, Indy's never seen a driver like this." ALL IMAGES BY NASA AND FILM SCANS BY THE JOHNSON SPACE CENTER UNLESS OTHERWISE NOTED



John Young works at the rover on the lower slopes of Stone Mountain in the Descartes Highlands, with the Cayley Plains spread out below him.

While Young and Duke waited for Mattingly to light Casper's *engine, the pair tried to wipe down Duke's helmet.*

YOUNG (ONBOARD LM): Ain't the clearest in the world, but it's the clearest I could do, Charlie. Honest.

DUKE (ONBOARD LM): It's terrible.

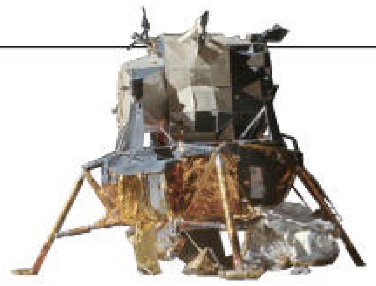
YOUNG (ONBOARD LM): You want to try it yourself? Just doesn't come off. […] OK, we're getting — we're getting behind the timeline probably — maybe.

DUKE (ONBOARD LM): No, we aren't. We're OK.

YOUNG (ONBOARD LM): OK, nothing we can do here, huh?

Onboard Casper, *Mattingly realized he had a problem. In the gimbal test, the second set of yaw gimbals was oscillating violently, causing the entire spacecraft to shake. Not knowing what the issue was, he started to blame himself. In 2001, he recalled: "[I've] practiced this stuff so much, it's like knowing your name. […] We had already done this a couple of times on our way out, so it's not like the first time we'd done this test, only this time the spacecraft was [shaking]. I stopped. [I thought,] 'Oh, God. I've done this a thousand times. How could I screw it up now? I've got to do this again.'"*

MATTINGLY (TO HIMSELF): *[garbled]* marked. *[garbled] [Long pause.]*



DUKE SAID IN A 1999 NASA ORAL HISTORY, "IF YOUR HEART CAN SINK TO THE BOTTOM OF YOUR BOOTS IN ZERO GRAVITY, OURS DID."

[garbled] yaw. *[garbled] [Pause.] [garbled] [Pause.]* It's not gonna work.

YOUNG (ONBOARD LM): *[sarcastically]* Charlie, this is fun, by golly. *[Laughs.]* It's really — it's really — it's the worst sim I've ever been in.

MATTINGLY (TO HIMSELF): I be a sorry bird.

MATTINGLY: Hey, *Orion*?

YOUNG: Go ahead, Ken.

MATTINGLY: I have an unstable yaw gimbal, no. 2. It's just been oscillating and — oscillates in yaw any time it gets excited.

YOUNG: Oh, boy.

MATTINGLY: You got any quick ideas?

YOUNG: No, I sure don't.

Unless the problem was resolved, mission rules dictated the landing could not continue.

While Mattingly tried to troubleshoot the gimbal problem with Houston, Young and Duke braced themselves for Houston to cancel their landing. "Our hearts sank," Duke said in a 1999 NASA oral history. "If your heart can sink to the bottom of your boots in zero gravity, ours did, because there we were, two years of training, 240,000 miles [386,000 km] away, an hour before the landing, on an orbit you can look down at your landing site, 8 miles [13 km] beneath you, and they're about to tell you to come home."

YOUNG (ONBOARD LM): Man, I'm ready. I'm ready to go down and land. I think that'd really be neat.

DUKE (ONBOARD LM): I bet we dock and come home in about three hours.

The crew spent one more trip around the Moon waiting in agony. When they came around the lunar farside on their 15th lunar orbit and reestablished radio contact with Houston, they got good news: The landing was back on.

IRWIN: We've run exhaustive tests down here, on the West Coast and East Coast on controllability aspects and structural aspects, and everything looks satisfactory. On Apollo 9, we ran — a similar test was run, as you probably remember. […] So we're convinced down here that we have a satisfactory control mode if we have to revert to that one. Over.

In Mission Control, Stuart Roosa, the Command Module Pilot for Apollo 14, took over the CapCom's mic to add more words of reassurance.

ROOSA: You know, Jim was talking about the Apollo 9 test, and he said that you really feel it in the spacecraft. But this thing is stable. They've really checked that out, and it'll rattle and roll a little bit if you have to use it, but it's stable.

MATTINGLY: Sounds good. Once again, the ground earns their pay.

From there, the landing was smooth sailing. The site was on the Cayley Plains, nestled between two peaks of the Descartes Highlands — Smoky Mountain to the north and Stone Mountain to the south. Each mountain sported a nearby crater with prominent rays — North Ray and South Ray craters. Geologists hoped these craters would serve as natural drill holes where the crew could find samples of the underlying bedrock. Young and Duke set Orion *down roughly 906 feet (276 m) from their target, near two craters named Double Spot.*

DUKE: Contact. Stop. Boom! PRO. ENGINE ARM. Wow! *[garbled]* man! Look at that! […]

APOLLO 16
YOUNG • MATTINGLY • DUKE

The crew of Apollo 16 (left to right): Command Module Pilot Thomas K. Mattingly, Commander John W. Young, and Lunar Module Pilot Charles M. Duke.

YOUNG: Well, we don't have to walk far to pick up rocks, Houston. We're among them. […]

DUKE: Old *Orion* is finally here, Houston. Fantastic!

IRWIN: Sounds great.

* * *

With the long delay, the crew opted to sleep and push back their first scheduled extravehicular activity (EVA) to the next day. The next morning, as Young clambered down the ladder, Duke couldn't wait to get onto the lunar surface.

DUKE: Hey John, hurry up!

YOUNG: I'm hurrying. OK.

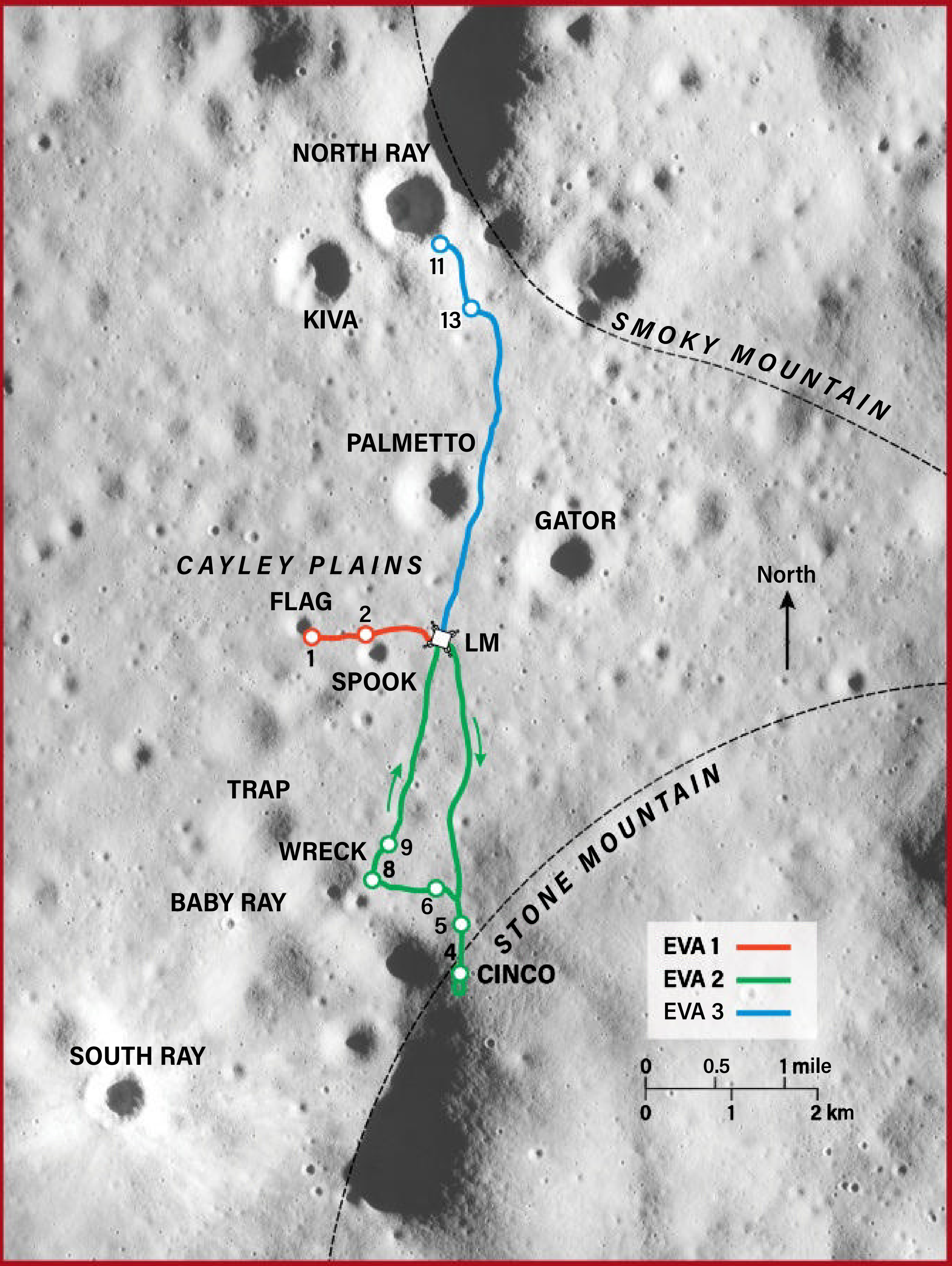
With that, Young stepped onto the Moon.

YOUNG: There you are, our mysterious and unknown Descartes. Highland plains. Apollo 16 is going to change your image.

Duke was next to bound down the ladder.

DUKE: Here I come, babe! […] Hot dog, is this great! […] Fantastic. That's the first foot on the lunar surface. It's super, Tony.

EXPLORING THE HIGHLANDS



The landing site for *Orion* was chosen due to its location at two overlapping geologic formations: the Cayley Formation and the Descartes Formation. Both were thought to be volcanic in nature — but this was quickly disproved by the dearth of volcanic rocks in the area. Instead, scientists suspect, the massive Imbrium impact 3.9 billion years ago blasted ejecta that flowed across the Moon, forming structures at Apollo 16's landing site that resemble volcanic flows. *ASTRONOMY:* ROEN KELLY

ANTHONY ("TONY") ENGLAND (CAPCOM): Sounds great.

Before they began their excursion, the pair set up the Apollo Lunar Surface Experiments Package (ALSEP), a suite of stationary scientific instruments. One highlight was an experiment developed by Columbia University's Marcus ("Mark") Langseth to measure the heat flow within the Moon's interior. It was an upgraded version of a kit that had flown on Apollo 15; on that mission, problems with the drill prevented the heat probes from being planted at their intended depth.

DUKE: OK. Man, you can't believe how happy I am that [the first drill stem] went in there.

YOUNG: Tony, he's very happy.

ENGLAND: Mark's pretty happy, too.

But as Young worked at the ALSEP's central station, with wires tangled at his feet, he accidentally caught his foot on a cable and stumbled.

YOUNG: Charlie …

DUKE: What?

YOUNG: Something happened here.

DUKE: What happened?

YOUNG: I don't know. Here's a line that pulled loose.

DUKE: Uh-oh.

YOUNG: What is that? What line is that?

DUKE: That's the heat flow. You've pulled it off.

YOUNG: I don't know how it happened. Pulled loose from there?

DUKE: Yes.

YOUNG: God almighty. Well, I'm wasting my time. I'm sorry. I didn't even know — I didn't even know it. *[Pause.]* It's sure gone —

ENGLAND: Did the wire or the connector come off?

YOUNG: — our first catastrophe. It broke right at the connector.

DUKE: The wire came off at the connector.

ENGLAND: OK, we copy. OK, I guess we can forget the rest of that heat flow.

DUKE: Now, if I go do the — ah, rats!

YOUNG: I'm sorry, Charlie. You know it.

Young took the mishap hard — he knew how hard Langseth and the other mission scientists had worked on the experiment. But there was nothing to do except carry on.

After deploying the rest of the ALSEP, the pair set out in the rover on their first traverse: a short excursion about 0.9 miles

(1.5 km) west to Flag Crater, a crater nearly 800 feet (240 m) wide. There, they hoped to collect samples representative of the Cayley Formation. One rock caught the eyes of the scientists in the backroom in Mission Control, led by geologist William Muehlberger.

ENGLAND: As you come around there, there is a rock in the near field on this rim that has some white on the top of it. We'd like you to pick it up as a grab sample.

DUKE: This one right here?

ENGLAND: That's it. […]

DUKE: OK, that's a —

YOUNG: That's a football-size rock.

DUKE: It's a "Great Scott" size.

On Apollo 15, Commander David Scott had collected the largest Moon rock to date.

YOUNG: Are you sure you want a rock that big, Houston?

ENGLAND: Yeah, let's go ahead and get it.

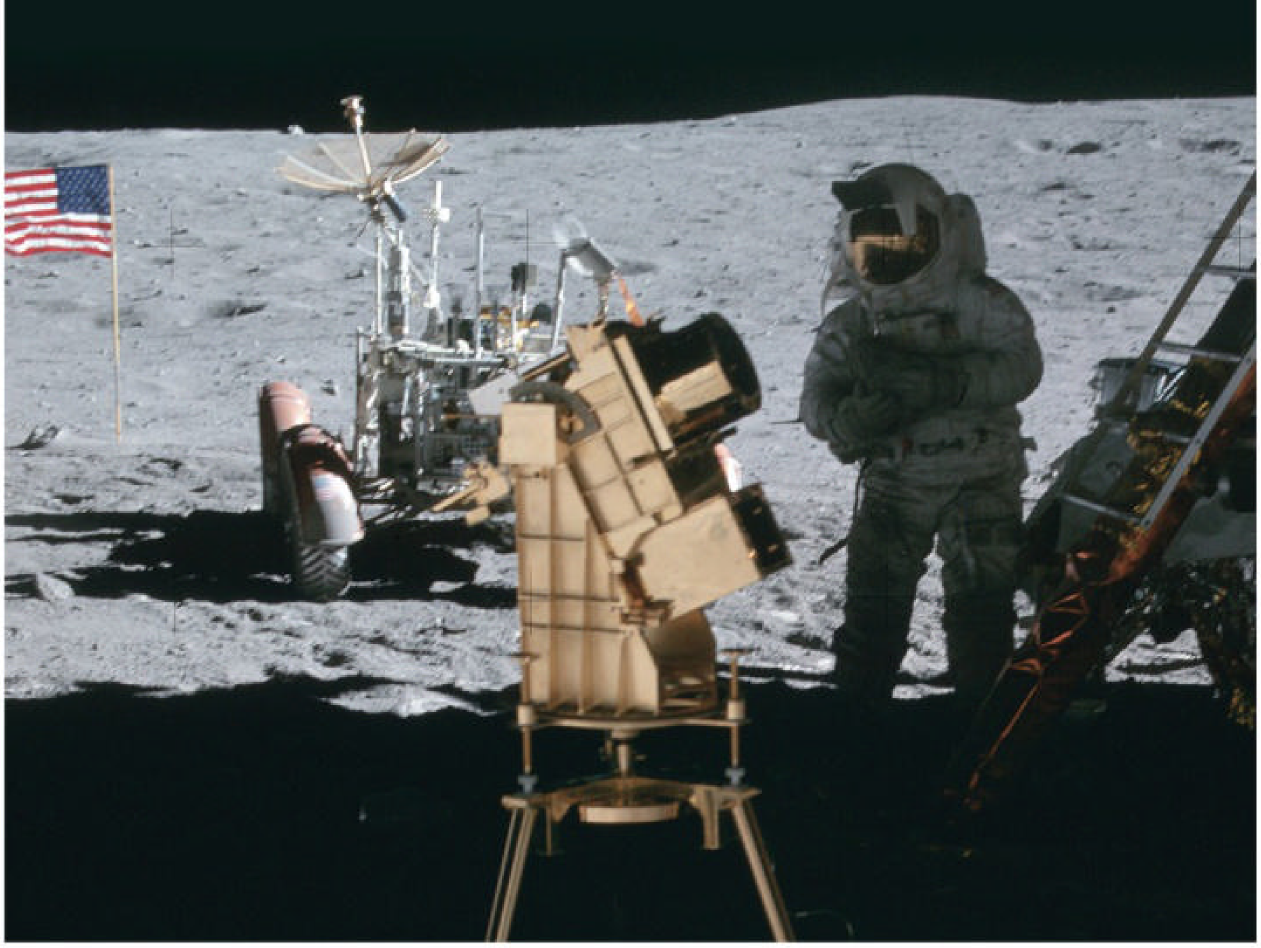
YOUNG: That's 20 pounds [9 kilograms] of rock right there.

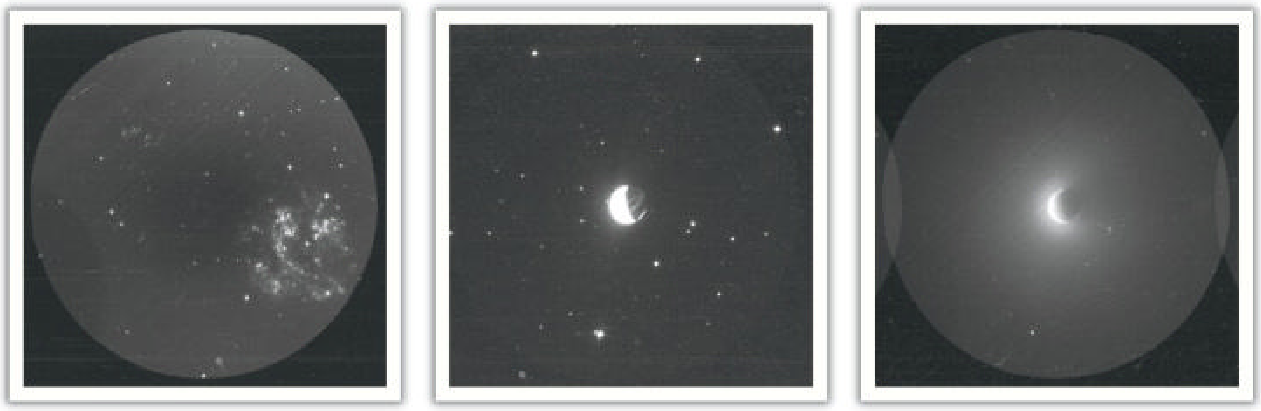
DUKE: OK. It has some big clasts in it, John.

YOUNG: It sure has.

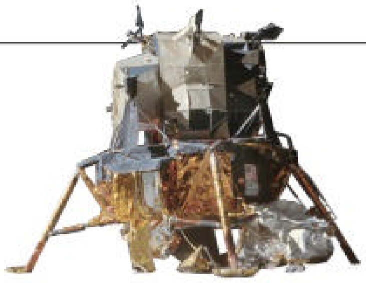
DUKE: If I fall into Plum Crater getting this rock, Muehlberger has had it.

ENGLAND: We agree.





Apollo 16 brought an astronomical telescope (top) to the Moon: a 3-inch, f/1.0 Schmidt far-ultraviolet camera with imaging and spectrographic modes. John Young set up the camera in the LM's shadow to reduce glare and aimed it manually. Objects observed include (bottom row, left to right): the Large Magellanic Cloud, Earth's tropical airglow, and polar aurorae.



UNBEKNOWNST TO YOUNG, HIS RADIO REMAINED OPEN, ALLOWING HOUSTON — AND THE PRESS CORPS — TO EAVESDROP ON A DECIDEDLY PRIVATE CONVERSATION.

DUKE: OK, I've got it. […] Oh, Tony, it's got some beautiful crystals in it though. That was a good guess.

ENGLAND: Good show.

In fact, this rock — dubbed "Big Muley" after Muehlberger — tipped the scales at almost 26 pounds (11.7 kg), setting a lunar sample weight record that has yet to be broken.

As the crew wrapped up their first EVA, the scientists in Mission Control were questioning some of their basic assumptions about Apollo 16's landing site. Perhaps the landscape wasn't as volcanic as they had thought: Nearly all the rocks the crew had found were breccias — cemented piles of smaller rock fragments that are non-volcanic in origin.

CapCom Henry Hartsfield relayed these impressions to Mattingly as he soared over the landing site in Casper.

HARTSFIELD: I guess the big thing, Ken, was they found all breccia. They found only one rock that possibly might be igneous.

MATTINGLY: Is that right? *[Laughs.]*

HARTSFIELD: Yeah. I guess the guys are a little bit surprised by that.

MATTINGLY: […] *[Laughs.]* Well, it's back to the drawing boards, or wherever geologists go.

Inside the LM, as Young and Duke prepared to sleep, Duke paid tribute to the mission geologists who had trained them.

DUKE: Let me say that all our geology training, I think, has really paid off. Our sampling is really — at least, procedurally — has been real team work, and we appreciate everybody's hard work on our sampling training.

ENGLAND: OK. And I sure think it's paying off. You guys do an outstanding job.

YOUNG: Yeah. You noticed how good I carried the bags, huh?

Unbeknownst to Young, his radio remained open, allowing Houston — and the press corps — to eavesdrop on a decidedly private conversation.

YOUNG: I got the farts again. I got 'em again, Charlie. I don't know what the hell gives it to me. Certainly not — I think it's the acid in the stomach. I really do.

DUKE: It probably is.

YOUNG: I mean, I haven't eaten this much citrus fruit in 20 years! And I'll tell you one thing, in another 12 f------ days, I ain't never eating any more! And if they offer to sup[plement] me potassium with my breakfast, I'm going to throw up! *[Pause.]* I like an occasional orange — really do. *[Laughs.]* But I'll be darned if I'm going to be buried in oranges.

After a few more minutes of unguarded conversation, Houston intervened.

JOE ALLEN (CAPCOM): *Orion*, Houston.

YOUNG: Yes, sir.

ENGLAND: OK, uh, John. You — we have a hot mic.

YOUNG: How… How long have we had that?

ENGLAND: OK. It's been on through the debriefing.

YOUNG: How could we be on hot mic with normal voice? […]

ENGLAND: John, would you exercise your push-to-talk button there? It may be stuck.

YOUNG: Yeah, I hit it then.

ENGLAND: John, it doesn't seem to be a hot mic now. Evidently, you got it off.

YOUNG: OK. Fine.

* * *

The next day, Young and Duke trekked to the lower slopes of Stone Mountain, 2.4 miles (3.8 km) south. Driving the rover up a 20 percent grade, they reached a cluster of five craters, called the Cincos, 500 feet (150 m) above the Cayley Plains. Their goal was to find chunks of the mountain's bedrock — true samples of the Descartes Highlands. However, this was complicated by the nearby presence of South Ray Crater on the plains below: The crew realized that many of the craters they were seeing were secondary craters formed by flying debris from the South Ray impact.

DUKE: You know, John, with all this — these rocks here, I'm not sure we're getting [samples of] Descartes.

YOUNG: That's right. I'm not either.

DUKE: We ought to go down to a crater without any rocks. […]

As Young and Duke stood at the rim of one secondary crater with a rake for collecting samples, they debated the best spot to sample from.

DUKE: This is steep. OK, where do you want this [rake]?

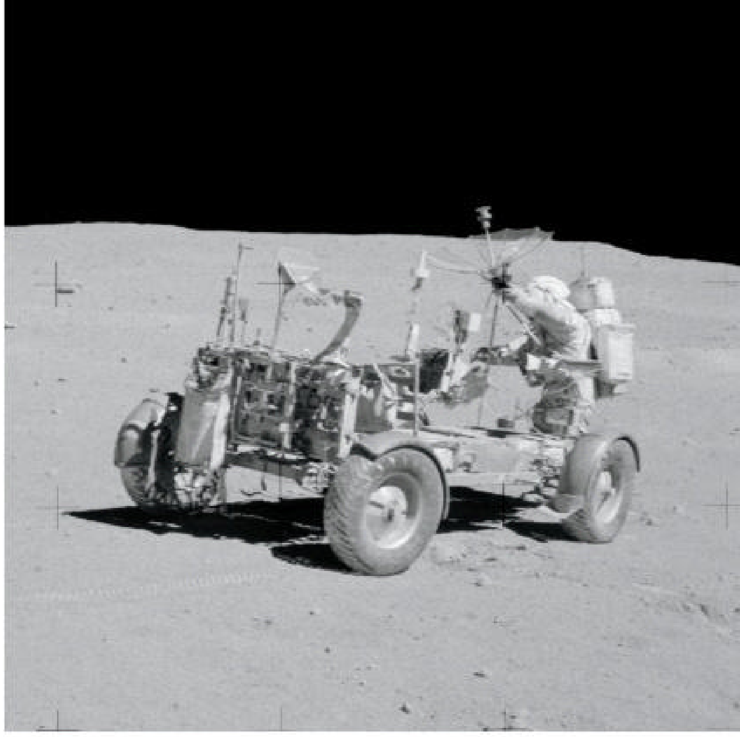
YOUNG: Well, on the rim, I think, Charlie.

DUKE: Why don't we get outside the rim? That would be definitely Descartes, right down here. OK?

YOUNG: The object is to get the stuff that's been knocked out of the ground [bedrock from the deepest point] and landed on the rim.

DUKE: Yeah, I know it, but I thought that would definitely — we could say that would be definitely — oh, OK, I'll sample right up here.

The next day's third and final EVA was originally going to be cancelled due to the landing delay, but it was retained at the insistence of the science team. They argued that EVA 3's main target, North Ray Crater, offered the mission's last, best chance to find Descartes bedrock material.



Indeed, North Ray Crater was a crown jewel of the area. At roughly 3,600 feet (1.1 km) in diameter, it was nearly as large as Arizona's Meteor Crater — and with even steeper slopes, as the pair found out.

YOUNG: Man, does this thing have steep walls.

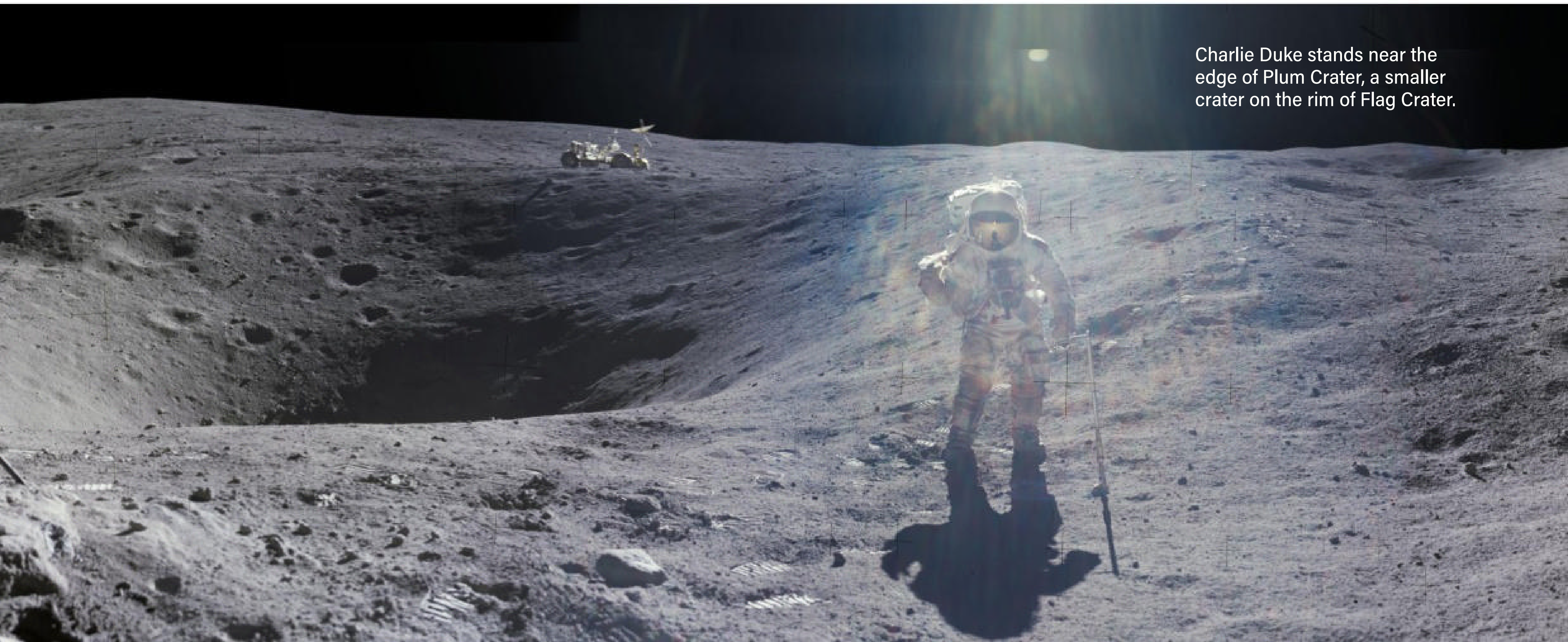
DUKE: They said 60 degrees.

YOUNG: Well, I tell you, I can't see to the bottom of it and I'm as close to the edge as I'm gonna get. That's the truth. […]

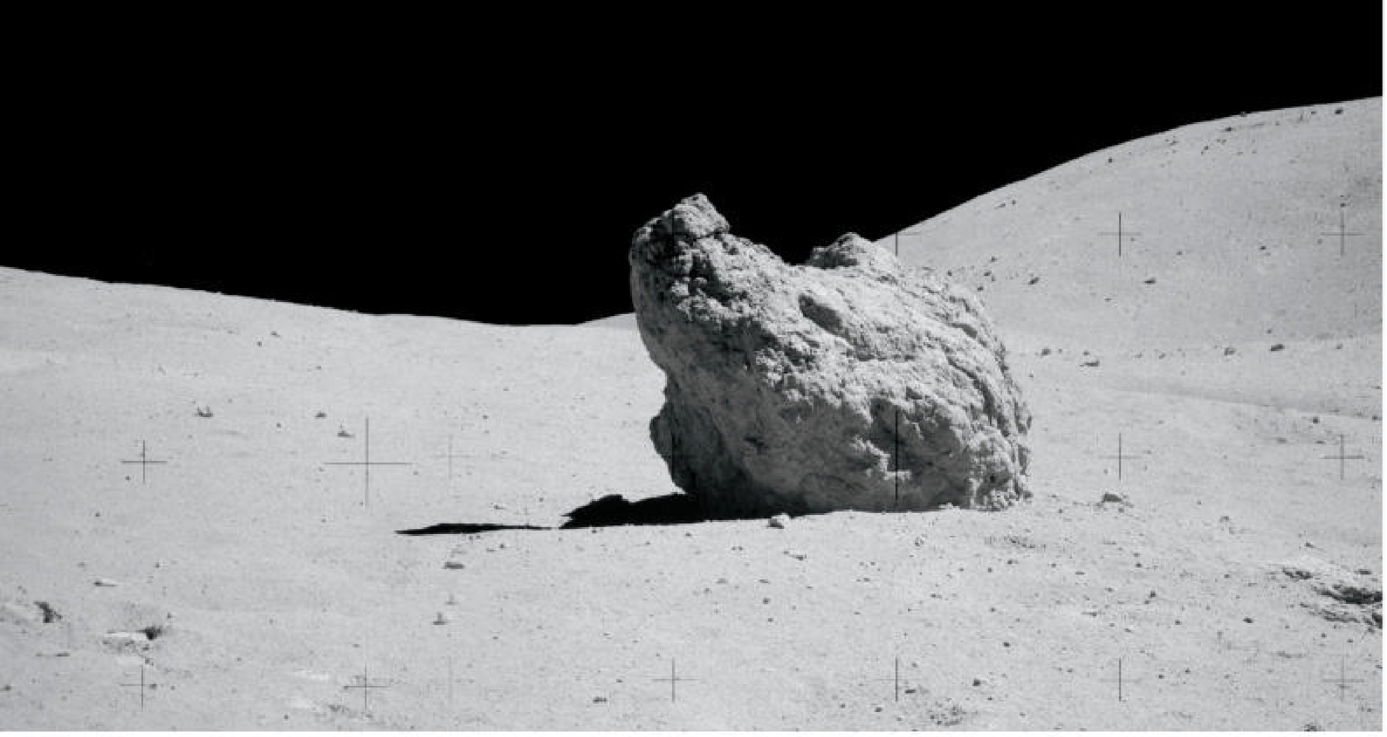
ENGLAND: Man, is that a hole in the ground!

DUKE: […] It really is. I see no bedrock, though. All I see is boulders around the crater. There's nothing that reminds me of bedding, just loose boulders.

Though no bedrock seemed available to sample, the crew took the opportunity to scout and sample an enormous boulder several hundred feet in the distance.



Charlie Duke stands near the edge of Plum Crater, a smaller crater on the rim of Flag Crater.



John Young adjusts the high-gain antenna on the lunar rover at Station 13 so that Houston can receive live images from the rover's TV camera. At right is a boulder named Shadow Rock. The astronauts sampled soil from its its shadow, hoping it was a permanently shadowed area where volatile gases could collect. NASA/LPI

LOSING HIS BALANCE, DUKE TOPPLED OVER BACKWARD, HIS LEGS FLAILING — AND HIS CRITICAL LIFE SUPPORT SYSTEMS IN HIS BACKPACK ABOUT TO IMPACT THE SURFACE.

DUKE: Look at the size of that biggie!

YOUNG: It is a biggie, isn't it. It may be further away than we think because —

DUKE: No, it's not very far. It was just right beyond you.

YOUNG: Theoretically, huh?

Apollo crews found it notoriously difficult to judge distances on the Moon. The lack of air meant distant terrain never appeared hazy as it would on Earth, robbing astronauts of a helpful distance cue.

DUKE: Look at the size of that rock!

ENGLAND: We can see.

DUKE: The closer I get to it, the bigger it gets.

Appropriately dubbed House Rock for its size, the boulder was one of the most impressive seen on any Apollo mission. Excavated by the North Ray impact, its samples gave scientists one of their best looks at lunar highlands material.

When Young and Duke returned to the LM, they had planned to stage a lighthearted "Lunar Olympics" for the TV camera. After all, 1972 was an Olympic year. But time was running short.

YOUNG: We were gonna do a bunch of exercises that we had made up as the Lunar Olympics to show you what a guy could do on the Moon with a backpack on, but they threw that out.

As Young talked, he decided to show off his high-jump abilities, repeatedly jumping up and down in front of the rover's camera.

ENGLAND: For a 380-pound [172 kg] guy [including the weight of the spacesuit], that's pretty good.

The camera panned over to Duke, who also started jumping up and down.

DUKE: Yeah, jump flat-footed straight in the air, three hundred — about 4 feet [1.2 m]. Wow!

Then, Duke had a brush with disaster. Losing his balance, he toppled over backward, his legs flailing — and his critical life support systems in his backpack about to impact the surface. "That was a moment of panic," he said in 1999. "I really — you know, I was in trouble. You could watch me scrambling like that, trying to get my balance. And my heart was just pounding. You know, the backpack is very fragile. I thought the suit would hold, but the backpack, with the plumbing and connections and all — if that broke, it was just like having a puncture in the suit."

YOUNG: *[disapprovingly]* Charlie!

DUKE: That ain't any fun, is it?

YOUNG: That ain't very smart.

DUKE: That ain't very smart. Well, I'm sorry about that.

YOUNG: Right. Now we do have some work to do.

After returning to the LM and securing their samples, Young and Duke immediately prepared to depart the Moon.

After a successful rendezvous with Casper, *the crew could reflect on what had been, despite all the gremlins, a successful field expedition. Over the course of 20 hours and 14 minutes of EVA, the rover covered 16.6 miles (26.7 km) and Young and Duke collected roughly 209 pounds (95 kg) of samples. The lack of igneous rocks suggested that Apollo 16's landing site had been shaped less by volcanoes and more by impacts and the resulting massive rock flows. It taught geologists an important lesson — that lunar terrain was more complex than it might appear from orbit.*

The next day, the crew lit the Service Module engine once more to begin their journey back to Earth.

On the mission's 11th day, less than 24 hours before Apollo 16 splashed down in the Pacific Ocean, the crew took part in a press conference, answering questions from reporters relayed to them by CapCom Henry Hartsfield. Though the press had many questions for the astronauts about the expedition's numerous technical glitches, the lead topic of that day's news cycle was clear.

HARTSFIELD: Apollo 16, the questions in this press conference have been prepared by newsmen covering the flight here at the Manned Spacecraft Center. I'm going to read them to you exactly as worded by the newsmen and in a priority specified by them. Question no. 1 for John Young: "A couple of times you were on hot mic and didn't know it, but how could a nice Florida boy like you say what you did about citrus fruit?"

CREW (ONBOARD): *[Laughter.]*

YOUNG: That's a very good question. Wait until you drink it day and night for two weeks and let me know what you think.

Mark Zastrow *is senior editor of* Astronomy.

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

In November 2019, Jupiter and Venus came within 1.4° of each other. This month brings a closer conjuntion, with just 12′ ultimately separating the pair. BILL HOOD

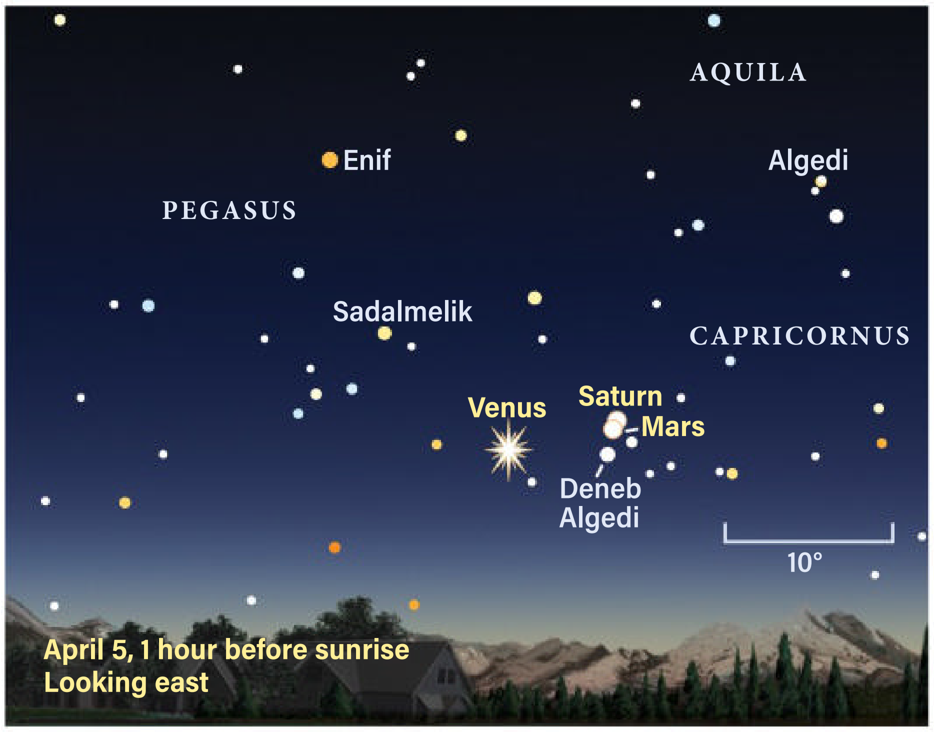
APRIL 2022

Venus and Jupiter meet

Mercury is at its best for Northern Hemisphere observers this month. It's a highlight in the evening sky. The rest of the planetary action takes place in the morning, with the finest conjunction of the year between the two brightest planets, Jupiter and Venus, on the last day of the month. In the run-up to that conjunction, Mars, Venus and Saturn open the month in a fine display that constantly changes appearance and makes April mornings a good time to spring out of bed early and catch the continuing spectacle each day.

Mercury achieves its best evening appearance of 2022 this month. Following its superior conjunction with the Sun on April 2, Mercury springs upward in the western evening sky and reaches greatest elongation just four weeks later. The high inclination of the ecliptic to the western horizon at this time of year further aids its visibility.

Movin' on by



On April 5, Mars (heading east) slides beneath Saturn. The planets are just 24' apart. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Can you spot Mercury at the end of April's first week? It shines at magnitude –1.8 and sets within 30 minutes of the Sun — certainly a challenge if your western horizon is blocked by trees or buildings.

Circumstances improve rapidly as Mercury climbs higher in altitude each consecutive evening. On April 9, it stands about 1° high 30 minutes after

OBSERVING HIGHLIGHT

VENUS and **JUPITER** are a mere 28' apart the morning of April 30. Follow them into daylight, and they'll grow even closer.

sunset but by the 13th, it's 5° high, shining at magnitude –1.4, and sets an hour after the Sun. By the 16th, it's an easy object, remaining above the horizon 75 minutes after sunset and magnitude –1.2. The misty glow of the Pleiades star cluster (M45) hangs some 18° above the planet. The cluster slowly appears as twilight darkens.

There's a rare chance on April 17, when Uranus and Mercury stand 2° apart and share a binocular field. **Uranus**, located 20 times farther than Mercury, is due south of the innermost planet and appears left of Mercury in the western sky. Begin searching around 8 P.M. local time to find Mercury about 10° high. As the sky darkens and the planet descends, look for Uranus to the left of Mercury — after 15 minutes, it should come into view. Uranus shines at magnitude 5.9 and becomes more difficult to see through low-altitude haze as time progresses. The ice giant stands a fraction of a degree north of Omicron (ο) Arietis, which is roughly the same magnitude, so search for two objects half a Moon's-width apart. The one closer to Mercury is Uranus.

Mercury's continued progress through the sky creates a lovely scene with the Pleiades later in the month. Beginning April 27, the planet lies within 2.5°

— *Continued on page 38*

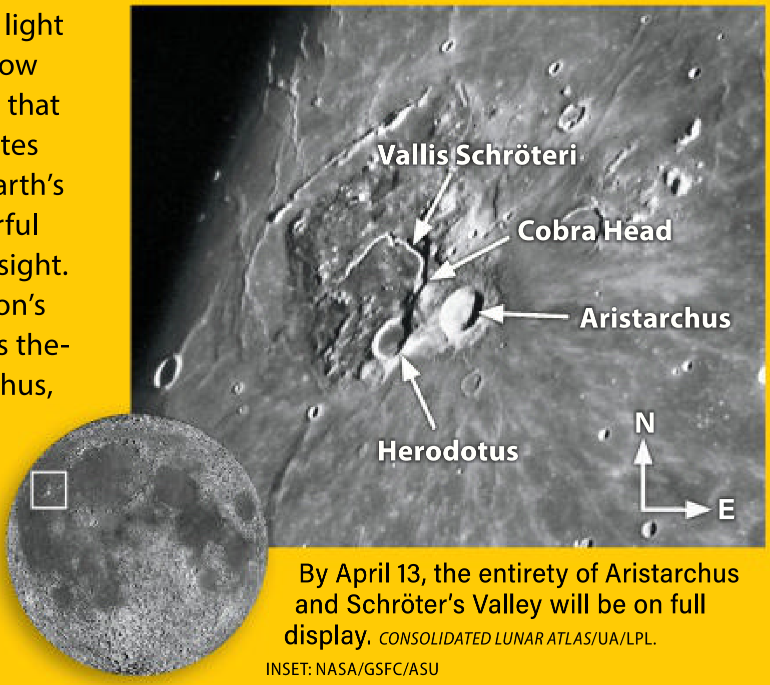
RISING MOON | Amazing Aristarchus

"THERE IS SOMETHING HAPPENING on the Moon!" Like so many observers before me, I was jolted by a striking blaze of flickering light on the terminator and called out to my fellow observers to come see. I am eager to relive that experience April 12, when the Sun illuminates the brilliant western flank of Aristarchus. Earth's turbulent atmosphere may add some colorful scintillation to produce a very memorable sight.

For a few moments, forget that the Moon's volcanoes are long dead and just enjoy this theatrical simulation of an eruption at Aristarchus, situated in the lunar northwest. Start right at sunset and continue to watch the visual drama unfold over the next few hours, as more of the rim appears and its inner walls light up. Generation after generation of smart, sharp-eyed astronomers managed to convince themselves there really was something going on here. Would you too have risen to that bait?

One evening later, look for a diamond-shaped plateau protruding above the surrounding lava-flooded plain. Just west of the blazing crater, note the long snakelike Vallis Schröteri (Schröter's Valley). This 6-mile-wide channel was carved out by a flow of lava that must have been truly awesome, dwarfing anything humans have witnessed on Earth. Nearest Aristarchus, it stops at a shadowed volcanic vent in a wider zone aptly named the Cobra Head.

Aristarchus

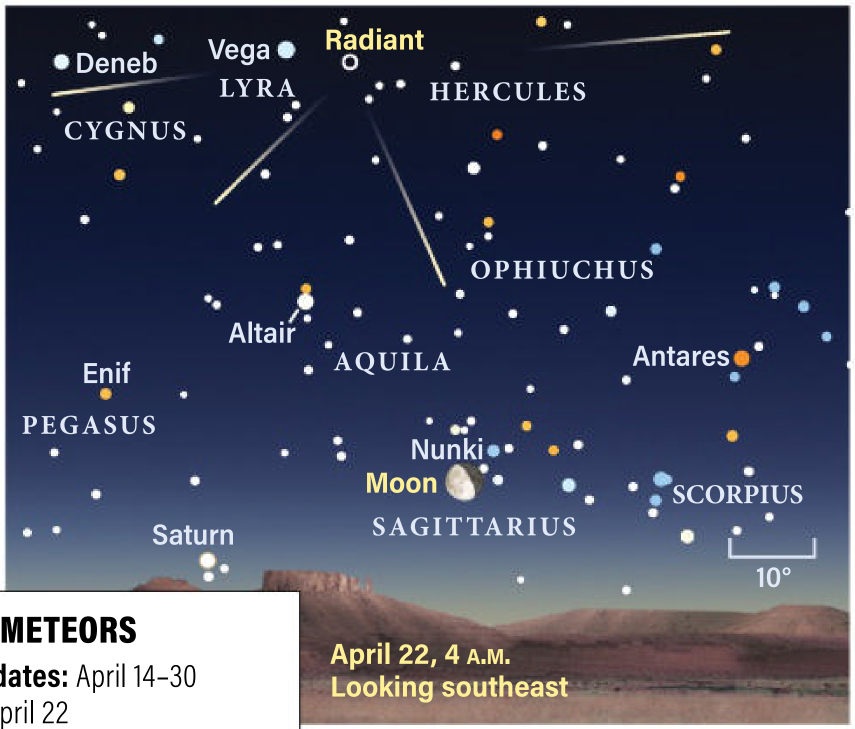


By April 13, the entirety of Aristarchus and Schröter's Valley will be on full display. *CONSOLIDATED LUNAR ATLAS/UA/LPL.*
INSET: NASA/GSFC/ASU

Aristarchus is so bright it is easily seen when the Moon is bathed in earthshine. Just after New Moon, the farside faces the Sun while the nearside experiences night. Yet Luna's familiar face is flooded with a blue-green light as it gazes at the nearly full Earth, poised almost motionless in the lunar sky. This happens on the 2nd, when the Moon is but a thin, waxing crescent in our evening sky. Train a scope on it and pick out the bright patch in the northwest. For fun, bump up the power and take a tour in this ashen light.

METEOR WATCH | Decent prospects

Lyrid meteor shower



The Moon remains at low altitude in Sagittarius as Lyra climbs to the zenith near dawn.

LYRID METEORS
Active dates: April 14–30
Peak: April 22
Moon at peak: Waning gibbous
Maximum rate at peak: 18 meteors/hour

THE ANNUAL LYRID meteor shower is active from April 14 to 30 and peaks the night of April 22. Its radiant rises in late evening and stands about 30° high at local midnight. This offers a few hours of dark skies before the 21-day-old Moon rises on the morning of the 22nd.

Meteors are always more prevalent in the hours before sunrise because the relative impact speed of shower particles on Earth's atmosphere is higher. As you prepare for the morning display of planets, which rises in the east soon after 4 A.M. local time, keep a lookout for the occasional flash from a Lyrid meteor. The Moon will slightly diminish the number of meteors you see. However, Lyra is above 80° in altitude by now, so you could catch 5 to 10 brighter shower members per hour.

STAR DOME

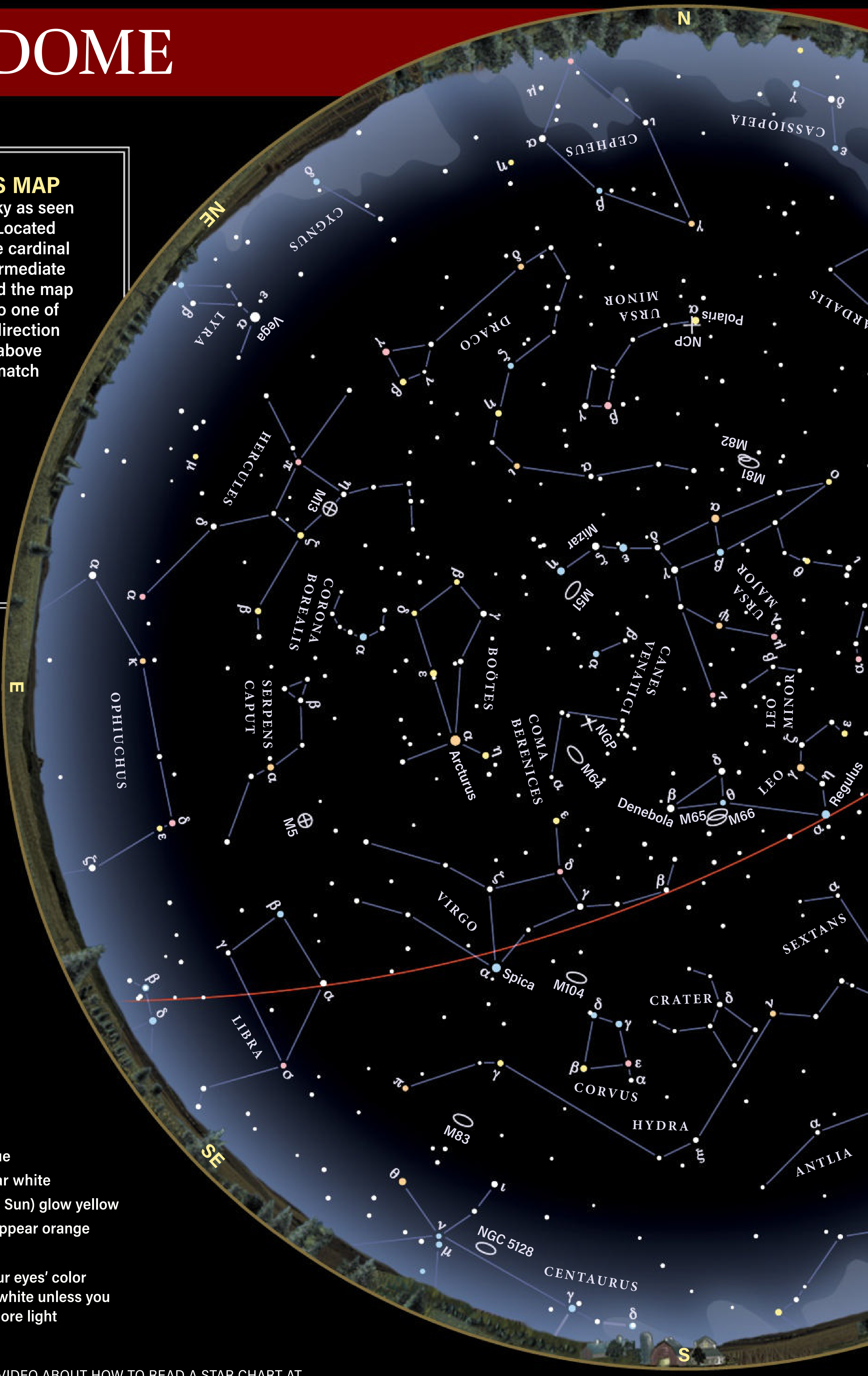
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight April 1
11 P.M. April 15
10 P.M. April 30

Planets are shown at midmonth


N
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CASSIOPEIA
CEPHEUS
CYGNUS
LYRA
Vega
DRACO
URSA MINOR
Polaris
NCP
M82
M81
HERCULES
M13
CORONA BOREALIS
SERPENS CAPUT
OPHIUCHUS
BOÖTES
Arcturus
CANES VENATICI
Mizar
M51
URSA MAJOR
LEO MINOR
COMA BERENICES
NGP
M64
LEO
Regulus
Denebola
M65
M66
M5
VIRGO
Spica
M104
LIBRA
SEXTANS
CRATER
CORVUS
HYDRA
M83
NGC 5128
CENTAURUS
ANTLIA

MAP SYMBOLS

◌ Open cluster
⊕ Globular cluster
☐ Diffuse nebula
⌖ Planetary nebula
⬭ Galaxy

STAR MAGNITUDES

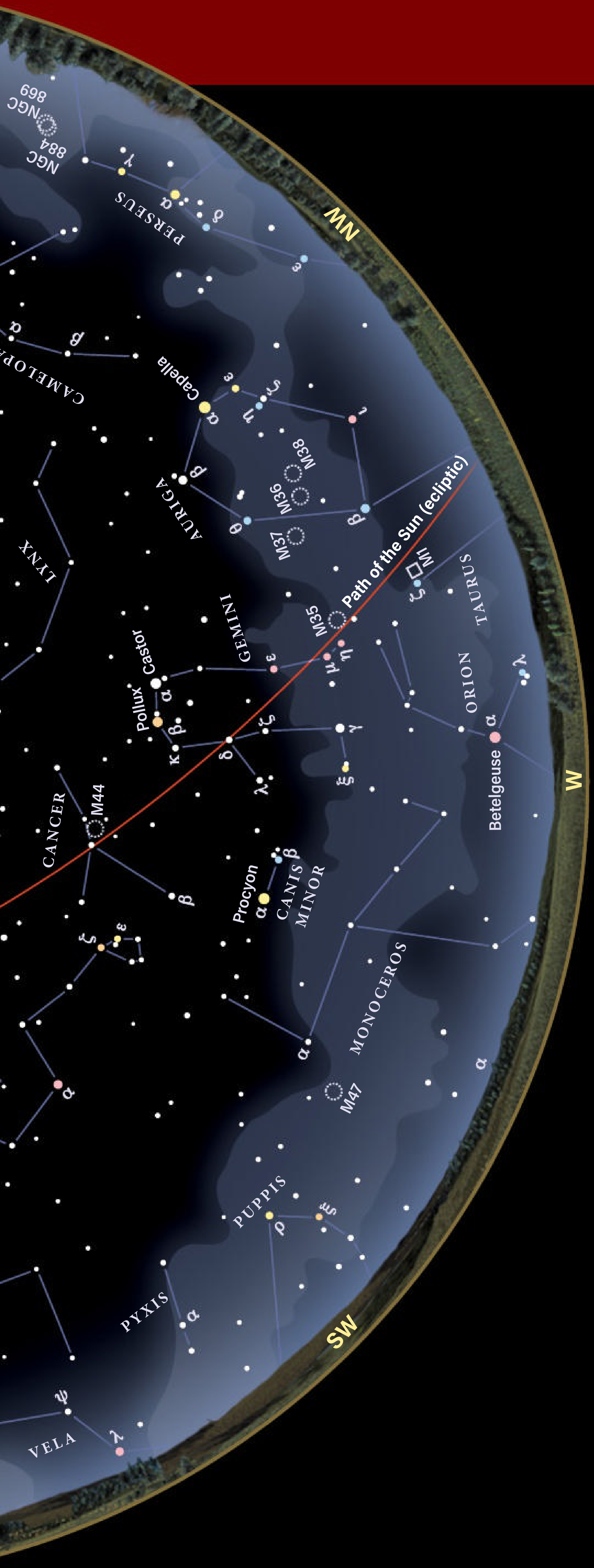
● Sirius
● 0.0 · 3.0
● 1.0 · 4.0
● 2.0 · 5.0

STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT
www.Astronomy.com/starchart.


NGC 869
NGC 884
PERSEUS
NW
CAMELOPA
Capella
AURIGA
M38
M36
M37
LYNX
Path of the Sun (ecliptic)
M1
TAURUS
GEMINI
M35
Castor
Pollux
ORION
Betelgeuse
W
CANCER
M44
Procyon
CANIS MINOR
MONOCEROS
M47
PUPPIS
PYXIS
SW
VELA

APRIL 2022

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
					🌑 1	🌑 2
🌒 3	🌒 4	🌒 5	🌒 6	🌒 7	🌓 8	🌓 9
🌔 10	🌔 11	🌔 12	🌔 13	🌔 14	🌕 15	🌕 16
🌕 17	🌖 18	🌖 19	🌖 20	🌖 21	🌗 22	🌗 23
🌗 24	🌘 25	🌘 26	🌘 27	🌘 28	🌑 29	🌑 30

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 🌑 New Moon occurs at 2:24 A.M. EDT

2 Mercury is in superior conjunction, 7 P.M. EDT

3 The Moon passes 0.6° south of Uranus, 1 P.M. EDT

4 Mars passes 0.3° south of Saturn, 6 P.M. EDT

6 The Moon passes 0.2° south of dwarf planet Ceres, 5 A.M. EDT

7 The Moon is at apogee (251,306 miles from Earth), 3:11 P.M. EDT

9 🌓 First Quarter Moon occurs at 2:48 A.M. EDT

11 Asteroid Pallas is in conjunction with the Sun, 11 P.M. EDT

12 Jupiter passes 0.1° north of Neptune, 4 P.M. EDT

16 🌕 Full Moon occurs at 2:55 P.M. EDT

19 The Moon is at perigee (226,890 miles from Earth), 11:13 A.M. EDT

22 Lyrid meteor shower peaks

23 🌗 Last Quarter Moon occurs at 7:56 A.M. EDT

24 The Moon passes 5° south of Saturn, 5 P.M. EDT

25 The Moon passes 4° south of Mars, 6 P.M. EDT

26 The Moon passes 4° south of Venus, 10 P.M. EDT

The Moon passes 4° south of Neptune, 11 P.M. EDT

27 The Moon passes 4° south of Jupiter, 4 A.M. EDT

Venus passes 0.007° south of Neptune, 3 P.M. EDT

28 Asteroid Hygiea is at opposition, 11 P.M. EDT

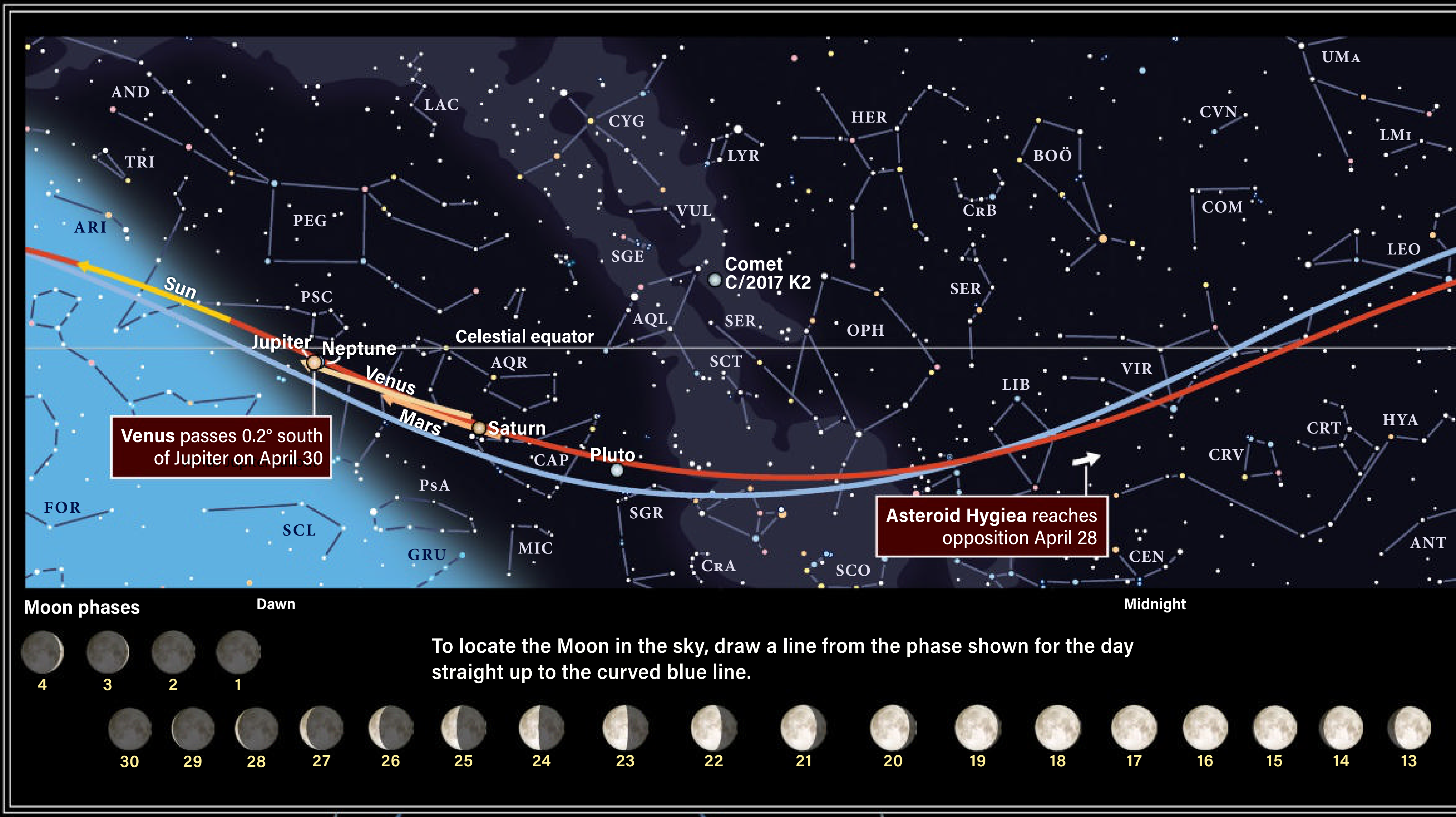
29 Mercury is at greatest eastern elongation (21°), 4 A.M. EDT

30 Venus passes 0.2° south of Jupiter, 3 P.M. EDT

🌑 New Moon occurs at 4:28 P.M. EDT; partial solar eclipse

Pluto is stationary, 5 P.M. EDT

PATHS OF THE PLANETS


AND
TRI
ARI
LAC
PEG
PSC
CYG
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VUL
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HER
BOÖ
CrB
SER
CVN
COM
UMa
LMi
LEO
Sun
Jupiter
Neptune
Venus
Mars
Saturn
Pluto
Comet C/2017 K2
Celestial equator
AQL
SER
SCT
OPH
AQR
CAP
LIB
VIR
CRT
HYA
CRV
PsA
FOR
SCL
GRU
MIC
SGR
CrA
SCO
CEN
ANT
Dawn
Midnight
Moon phases
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3
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29
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13

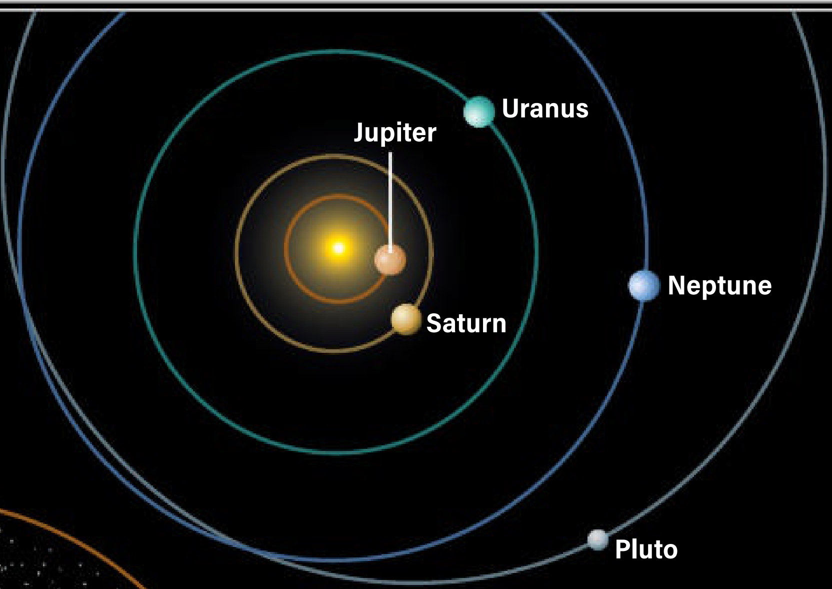
Venus passes 0.2° south of Jupiter on April 30

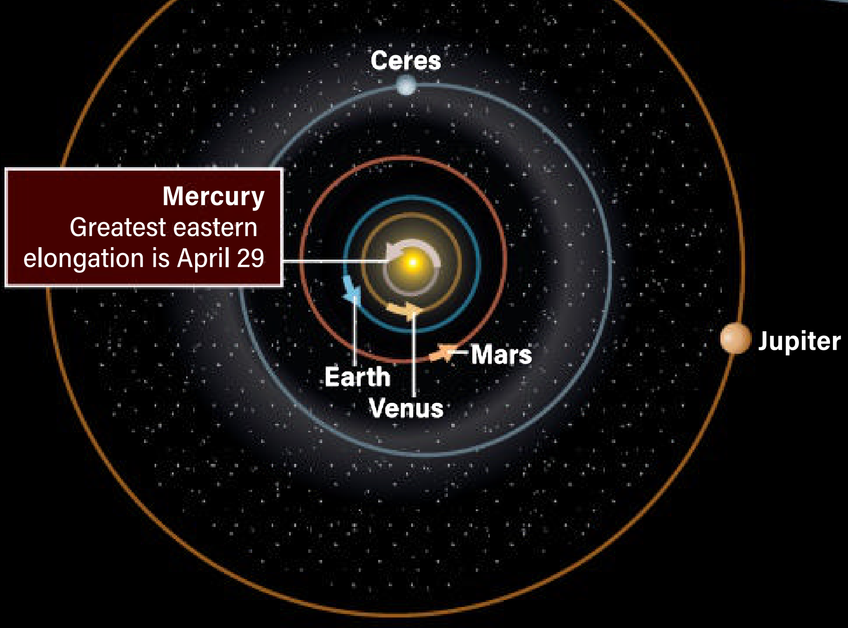
Asteroid Hygiea reaches opposition April 28

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.

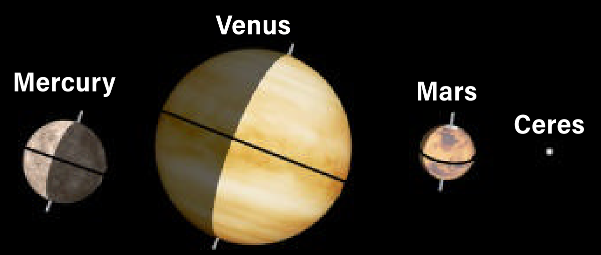

Uranus
Jupiter
Neptune
Saturn
Pluto


Ceres
Earth
Mars
Venus
Jupiter

Mercury Greatest eastern elongation is April 29

THE PLANETS IN THE SKY

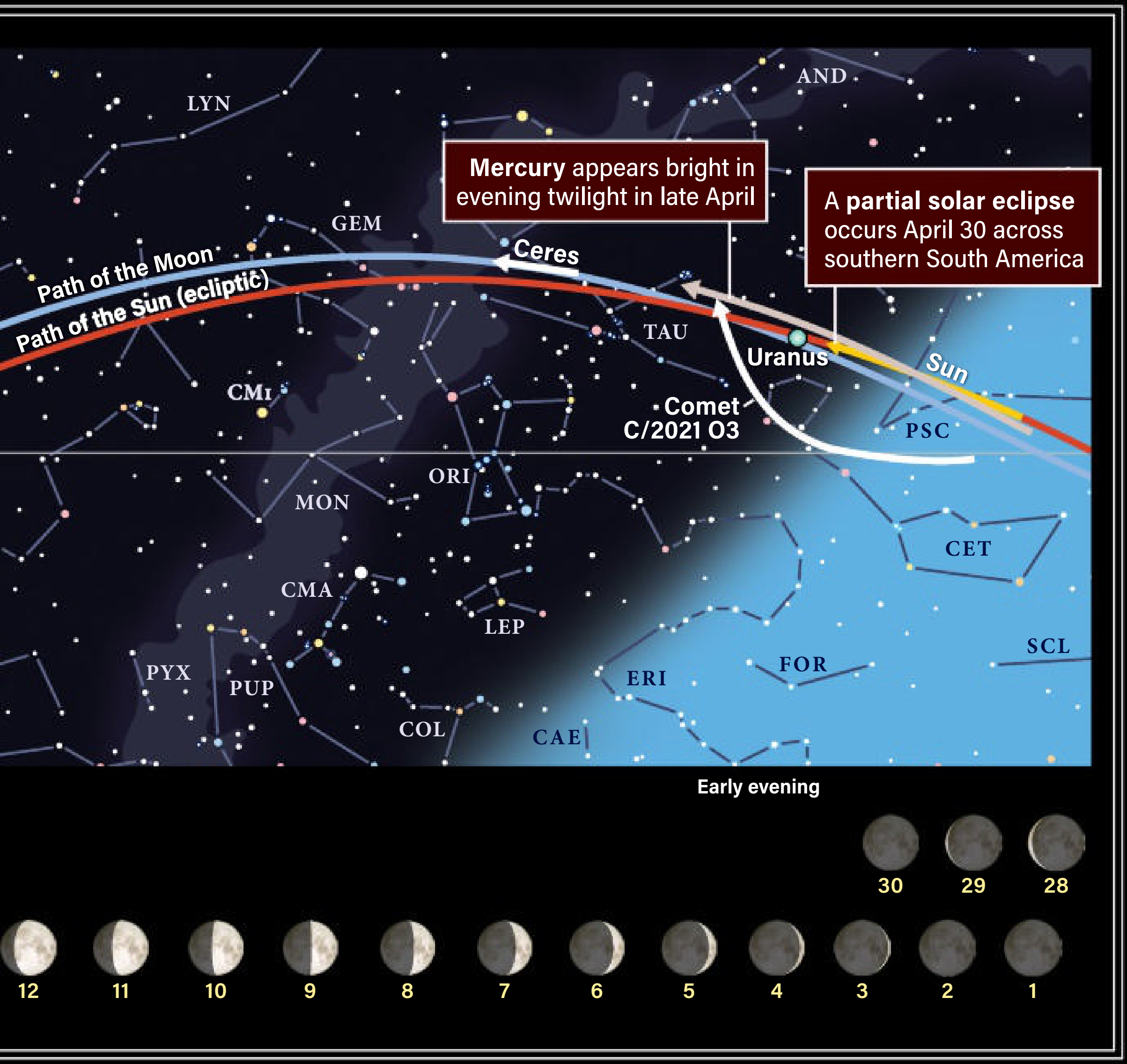
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.


Venus
Mercury
Mars
Ceres

PLANETS	MERCURY	VENUS
Date	April 30	April 15
Magnitude	0.3	–4.2
Angular size	8.0"	19.0"
Illumination	36%	61%
Distance (AU) from Earth	0.838	0.877
Distance (AU) from Sun	0.370	0.727
Right ascension (2000.0)	3h47.8m	22h46.1m
Declination (2000.0)	22°45'	–8°10'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

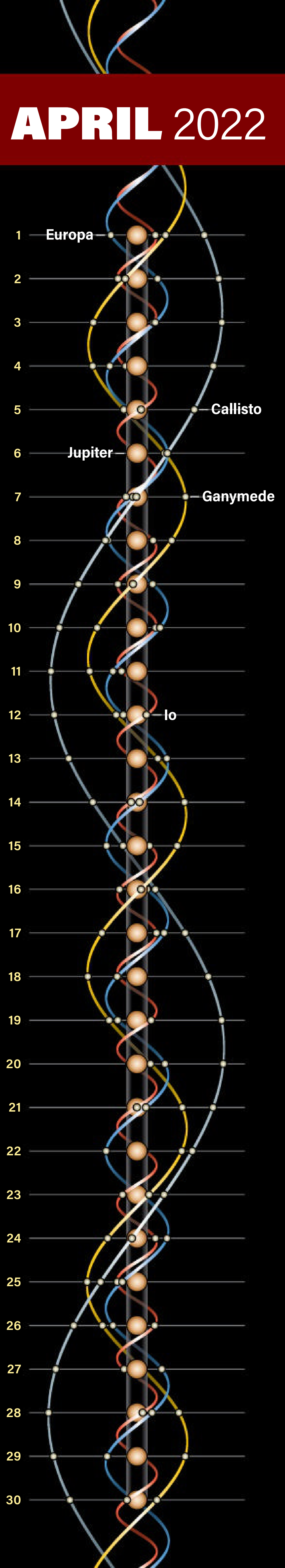
APRIL 2022


LYN
AND
GEM
Mercury appears bright in evening twilight in late April
A **partial solar eclipse** occurs April 30 across southern South America
Path of the Moon
Path of the Sun (ecliptic)
Ceres
TAU
Uranus
Sun
CMi
Comet C/2021 O3
PSC
ORI
MON
CET
CMA
LEP
PYX
PUP
SCL
FOR
ERI
COL
CAE
Early evening
30
29
28
12
11
10
9
8
7
6
5
4
3
2
1

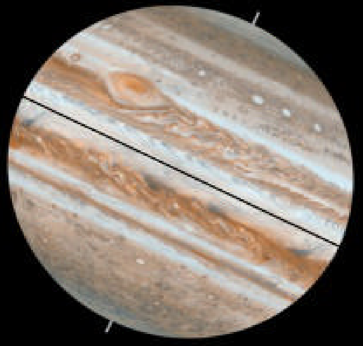
Callisto
Europa
Io
Ganymede

JUPITER'S MOONS

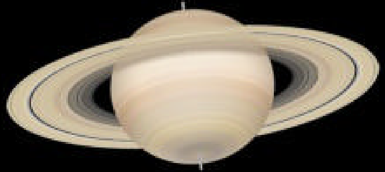
Dots display positions of Galilean satellites at 6 A.M. EDT on the date shown. South is at the top to match the view through a telescope.

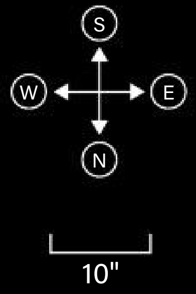


Jupiter

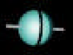


Saturn





Uranus



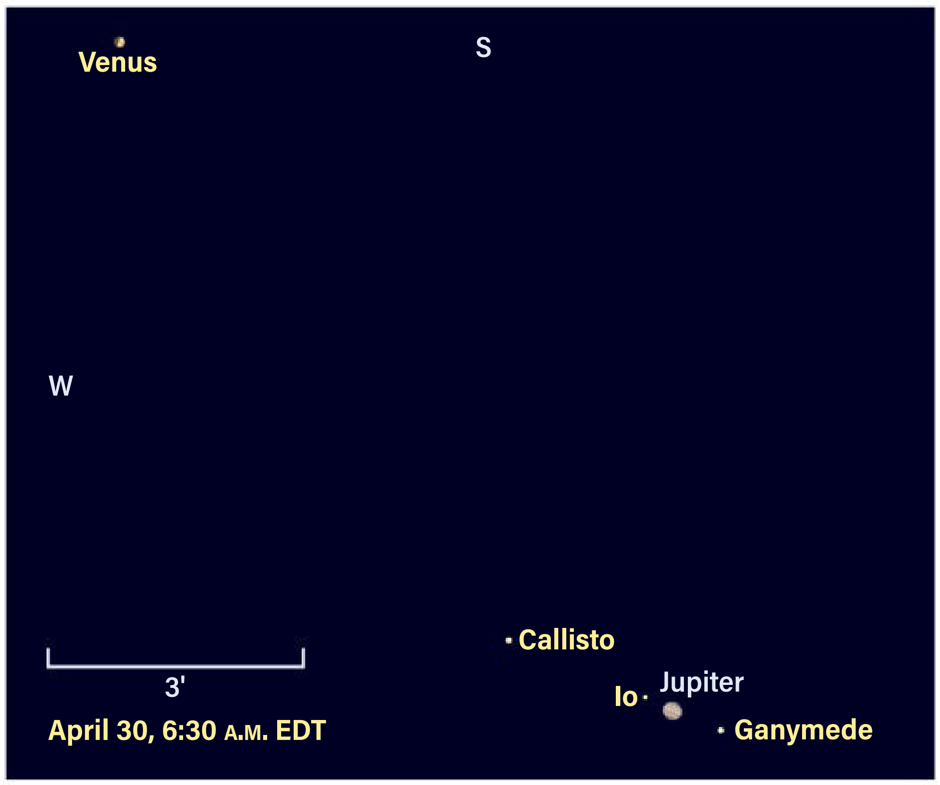
Neptune

Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
April 15	April 15	April 15	April 15	April 15	April 15	April 15
1.0	8.9	–2.1	0.7	5.9	7.8	15.2
5.4"	0.4"	33.9"	16.1"	3.4"	2.2"	0.1"
91%	98%	100%	100%	100%	100%	100%
1.722	3.115	5.812	10.332	20.656	30.774	34.550
1.413	2.639	4.974	9.897	19.708	29.918	34.503
22h08.8m	5h06.4m	23h40.4m	21h42.3m	2h44.0m	23h38.9m	20h03.0m
–12°54'	25°17'	–3°15'	–14°48'	15°30'	–3°31'	–22°24'

— *Continued from page 33*

A close conjunction



On April 30, zoom in on Jupiter and Venus — less than a Moon's width apart — to see both planets and several of Jupiter's moons. Those who look earlier or later than the time shown may catch Europa as well.

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)
Uranus (west)

MORNING SKY
Venus (east)
Mars (east)
Jupiter (east)
Saturn (southeast)
Neptune (east)

of the cluster and closes in to sit 1.5° due south on April 29. The same evening, Mercury attains its greatest eastern elongation of 21° from the Sun. By the end of the month, the small planet has faded to magnitude 0.5 and stands 8° high an hour after sunset.

Track Mercury with a telescope to watch its month-long series of changes, as it morphs from a fully lit disk spanning 5" on April 1 to a 33-percent-lit crescent 8" wide by April 30.

Set an early alarm to catch the remarkable collection of planets that congregate in the predawn sky this spring. Venus, Mars, and Saturn are up together, located in eastern Capricornus the Sea Goat.

Mars rises first on April 1, shortly before 5 A.M. local time. It's followed by **Saturn** and **Venus** within few minutes of each other, all about two hours before sunrise. Venus will be most obvious if you have any early morning haze, as it is a dazzling object at magnitude –4.4. Saturn, at magnitude 0.7, lies less than 4° to the right (southwest) of Venus. Mars is a relatively dim 1.1 and stands 2.4° to the upper right (west) of Saturn. Note that the Red Planet is too small for decent telescopic views. It will reach opposition at the end of the year.

The distance between Venus and Mars is just over 6°. As the three planets clear the horizon over the next hour, they're a sight to behold. By the start of nautical twilight, around 5:45 A.M. local time for latitudes near 40° north, the trio stands nearly 10° high in the eastern sky. Capricornus has never looked so bright.

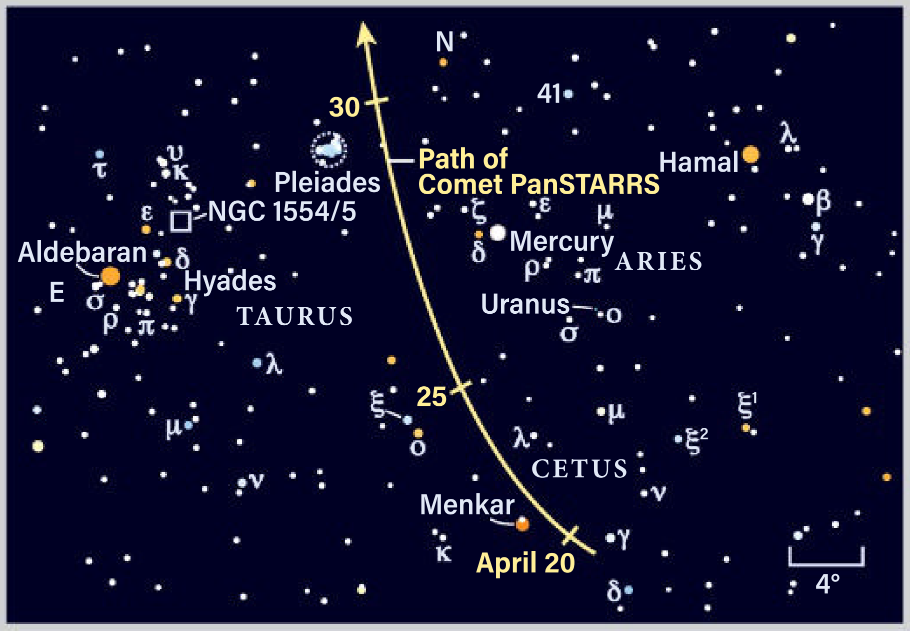
As April progresses, Venus and Mars continue to trek eastward against the starry background, while the more distant Saturn barely moves at all. By April 5, Mars and Saturn meet, moving from 30' apart on April 4 to 24' apart on April 5. Mars spans 5", while Saturn's disk is 16" wide, even though Saturn is more than five times farther from Earth than Mars. Note their color contrast — the ruddy surface of Mars reflects sunlight differently than the yellowish clouds of Saturn.

Beginning April 4, Venus moves into Aquarius and

Jupiter and Venus will not come this close while far from the Sun until 2039.

COMET SEARCH | Better than NEOWISE?

Comet C/2021 03 (PanSTARRS)



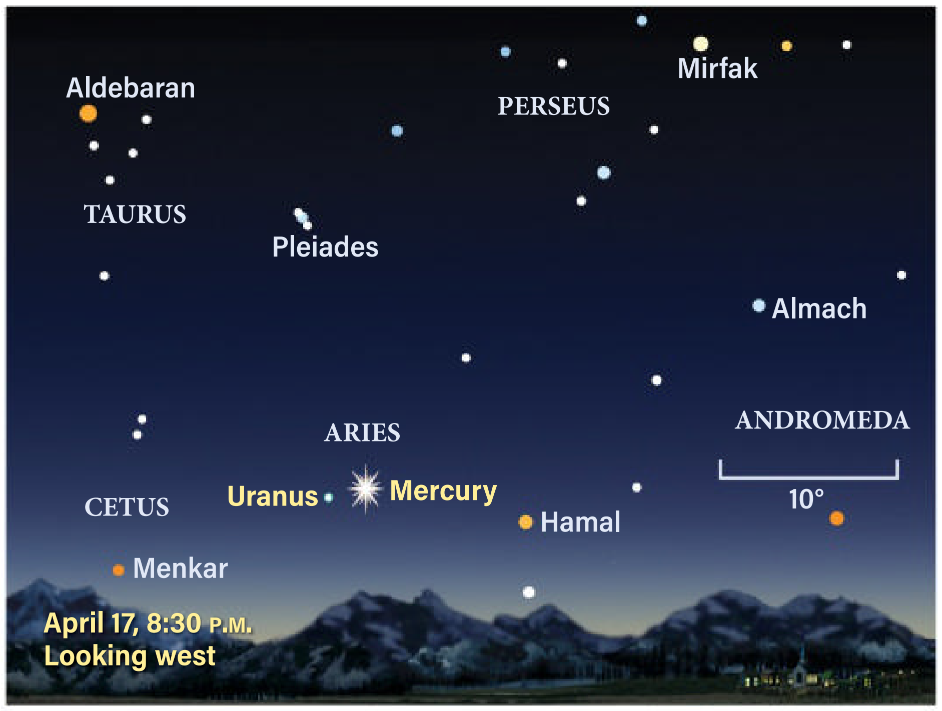
Comet PanSTARRS' action happens with Mercury and the Pleiades (M45) nearby, along with a crescent Moon May 2. The positions and relative magnitudes of Mercury and Uranus are shown here on April 21.

IT'S A FOOL'S ERRAND to think one can reliably predict a comet's maximum brightness, but C/2021 O3 (PanSTARRS) has the right characteristics on paper to become the comet of the decade. Could it fizzle? Yes. But with potential disappointment in mind, let's hope the following evening scenario comes to pass.

Those south of the equator get the first glimpse on the 10th with binoculars, watch it flower into a wonderful sword straight up from the horizon, then all but lose it by the 30th. In the lowest 48 states, the core may rival Mercury on the 21st, as the comet reaches its closest point to the Sun. An ion or sharp dust tail could become visible as twilight deepens. The rest of North America joins in on the 23rd or 24th, when the comet is at peak brightness. Ensure you are away from the city with a clear western horizon shortly after sunset. The comet sets all too quickly as twilight deepens.

Don't worry about fading post peak: PanSTARRS climbs into a darker sky night after night, increasing the contrast of its tails against the deep blue twilight. When comets pass between us and the Sun, the brightness boost from forward scattering can be amazing. The geometry is only a bit less favorable and it could last through the first week in May. Consider traveling if you must for this spectacle!

Near and far



Observers can use Mercury as a signpost to find the distant ice giant Uranus in the evening twilight later this month.

continues its eastward path, extending its distance from the Red Planet. Mars crosses into Aquarius April 12 and lies 9.5° west of Venus on that date, while Saturn stands 5° west of Mars. A waning Moon joins the scene on April 24, less than 9° from Saturn. The following morning, April 25, the Moon has shifted east and lies below the line connecting Mars and Saturn, with the planets standing 8.5° northeast and northwest of the Moon, respectively. Venus and **Jupiter** are just 5° apart the same morning, offering a tantalizing prelude to an amazing conjunction a few days later.

On April 27, a 26-day-old crescent Moon sits 4° below Jupiter, with Venus 3° to the gas giant's west. The planetary pair rises in a dark sky around 4:30 A.M. local time, followed by the crescent Moon 20 minutes later. As civil twilight begins, the planets stand 11° high in the eastern sky, with the beautiful Moon, earthshine illuminating its dark hemisphere, hanging below them. Jupiter shines at magnitude –2.1, compared with Venus at magnitude –4.1.

Don't forget to grab binoculars or your telescope that morning, because there's another planet in the same area: **Neptune** sits less than 24' from Venus. At magnitude 7.8, Neptune is a binocular object and the advancing twilight will cause it to fade out of view, so catch it within an hour of Venus rising. A telescope will show the pair nicely, Neptune's bluish glow contrasting spectacularly with the brilliant white of Venus, whose 66-percent-lit gibbous disk spans 17". Neptune is just 2" wide and is difficult to resolve at such a low altitude.

The grand finale of April's planetary events occurs on the 30th with a conjunction of the two brightest planets, Venus and Jupiter. Venus shines at magnitude –4.1 and Jupiter is dimmer but still brilliant at magnitude –2.1. They're just 28' apart, less than the width of the Full Moon. Jupiter spans 35" and is accompanied by three of the four Galilean moons: Io, Ganymede, and Callisto. Europa is hidden behind the planet for Midwestern observers; those on the East Coast will see Europa disappear behind Jupiter, while western skywatchers see its reappearance. Venus now shows a 67-percent-lit disk 17" wide.

Follow the pair into twilight and even after sunrise — if your telescope is tracking, you can continue view these bright planets into daylight. This is worthwhile because around 3 P.M. EDT (12 P.M. PDT), the two planets are only 12' apart, with Jupiter due north of Venus. While there are more conjunctions visible in the next few years between these planets, none come this close at an elongation well away from the Sun until November 2039.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Wichita, Kansas.* ***Alister Ling****, who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS

Still on the Bull

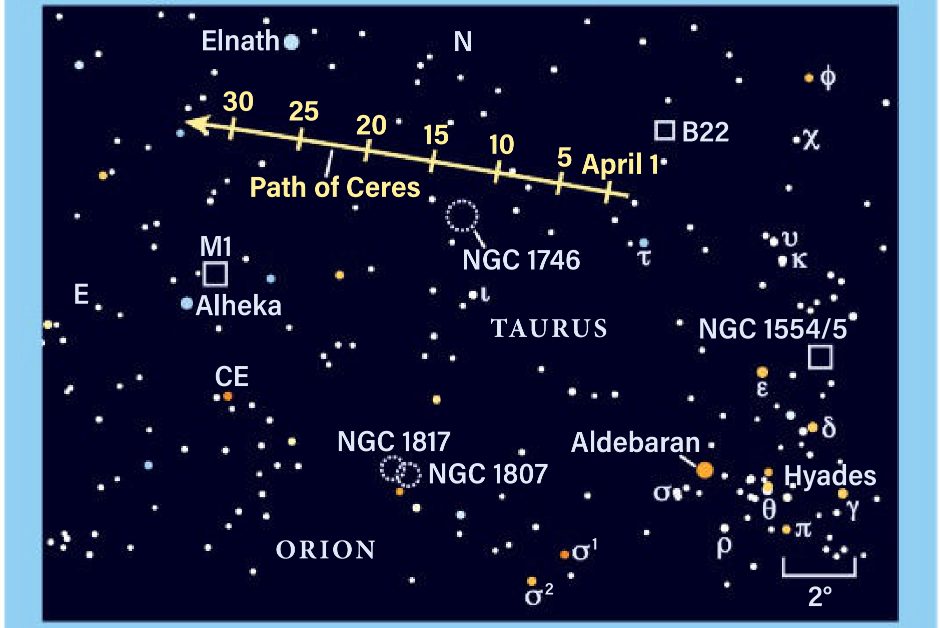
AS DARKNESS FALLS, dwarf planet 1 Ceres stands halfway up the western sky. It's above Aldebaran, crossing the northern horn of the celestial bull. Barely fading from a modest magnitude 8.9, Ceres is a good target for a small scope from the suburbs. In a nice coincidence, it is passing in front of the sprawling dark nebula Barnard 22, a huge zone of dust and gas that many million years from now will light up with brand-new massive stars.

To see the ruler of the asteroid belt shift relative to the stars in one session, try the nights of April 7 and 8. Make a simple sketch of the five brightest stars in the field and come back in two hours to identify the moving one.

On the evenings of the 11th through the 13th, drop south one degree to notice a widely scattered spray of stars a bit brighter than Ceres, covering almost two apparent moonwidths of sky. This is the open cluster NGC 1746. With his narrower field of view and darker sky, the skilled visual observer William Herschel discovered two separate concentrations of stars within the larger object. These and B22 do require a darker sky.

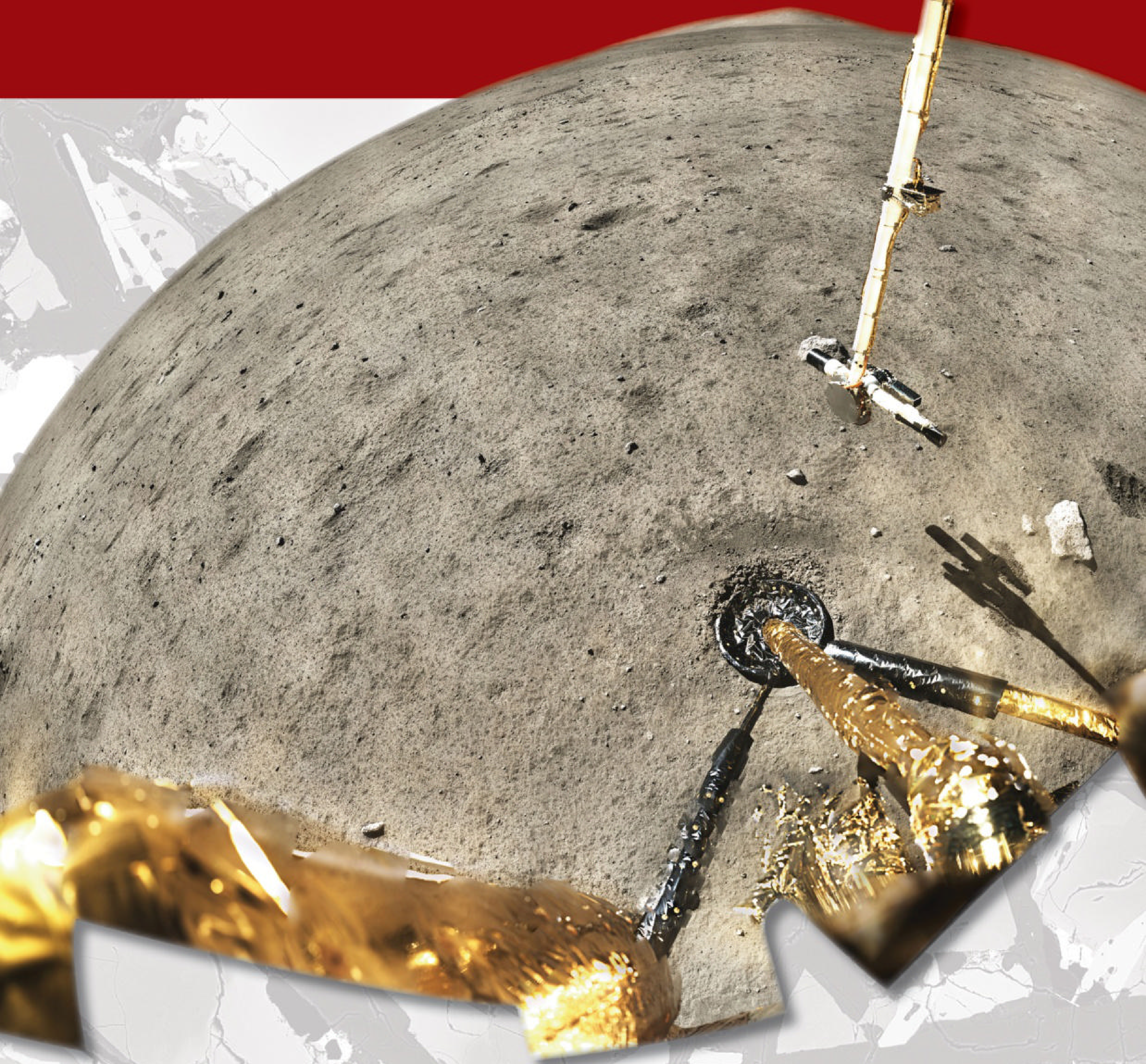
When Ceres returns to opposition next spring, it will be the closest it's been since 2005, glowing at magnitude 7 — nearly the brightest it can ever get.

Dark clouds and bright stars



Ceres is easy to find this month, traveling through a region where the rich Milky Way background is obscured by dark dust clouds.

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**



CHANG’E 5 rewrites lunar

history

The mission's samples are the youngest lunar rocks yet found, leaving scientists wondering how the Moon stayed hot for so long.

BY MARK ZASTROW

IN DECEMBER 2020, China's Chang'e 5 mission touched down northeast of the ancient volcano formation Mons Rümker in northern Oceanus Procellarum — a region of the Moon that was once a vast plain of molten lava. The site had been targeted by scientists for decades: Curiously, the surface there is somewhat sparse of impact craters, suggesting that its last lava flood occurred quite recently, in lunar terms. Determining its age was one of the mission's top priorities.

In all, the Chang'e 5 lander scooped and drilled 3.8 pounds (1.7 kilograms) of lunar material, which its return stage delivered to the grasslands of Inner Mongolia Dec. 16, 2020. They were the first Moon rocks returned to Earth since the Soviet robotic mission Luna 24 in 1976. Chang'e 5's samples were collected and parceled out to several research groups around the world. Now, scientists are beginning to report what they have found.

The first major scientific paper detailing mission findings was published Oct. 7 in *Science*, followed by a trio of papers in *Nature* Oct. 19. The *Science* paper found that the samples confirm the relative youthfulness of the landing site's volcanic basalt rocks: 1.96 billion years old, give or take a few tens of millions of years. One of the teams publishing in *Nature* independently found nearly the same result: 2.03 billion years, give or take 4 million years. This is about a billion years younger than any of the volcanic lunar samples returned by the Apollo and Luna missions.

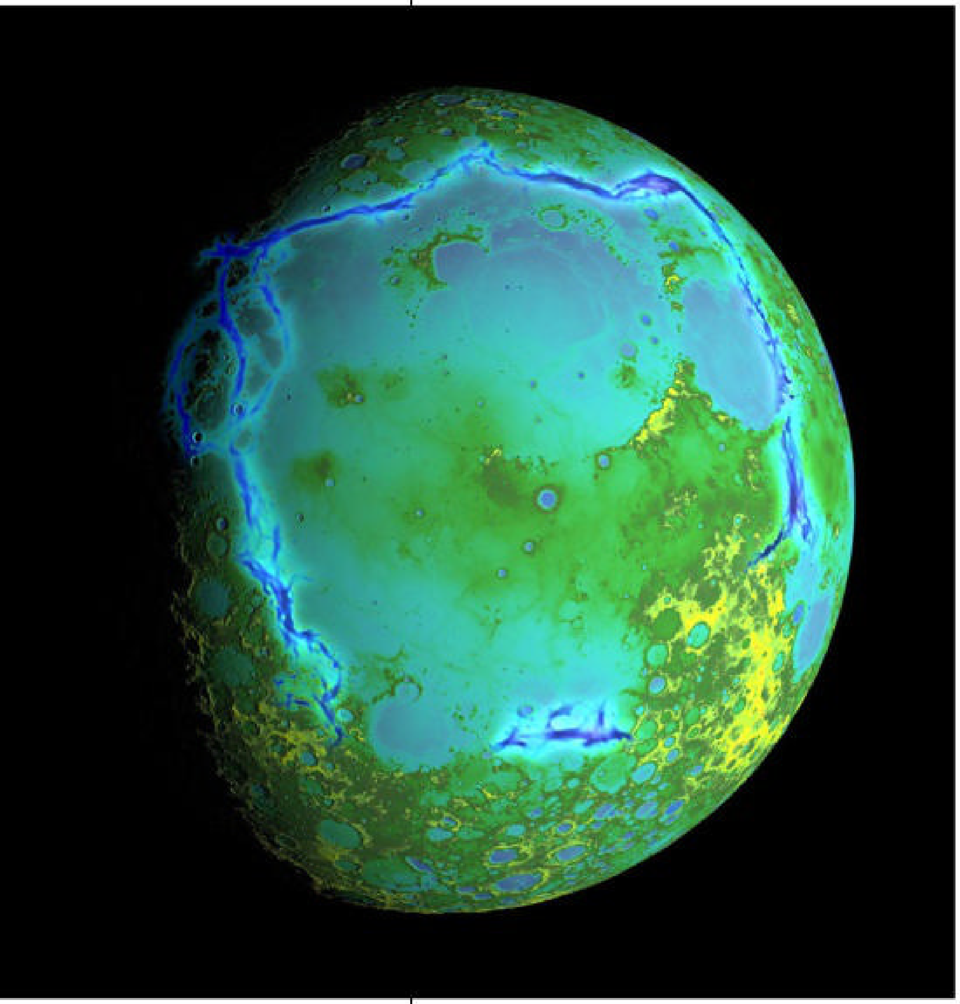
These findings indicate that volcanoes were erupting on the Moon just 2 billion years ago — which throws a wrench into our understanding of how bodies like planets and moons form. Scientists think that when such bodies are young, radioactive uranium and thorium sink deep into their interiors. These slowly decay and release heat, which can keep the mantle molten for billions of years. But models suggest that a body as small as the Moon should have lost all of its heat by then.

"We always said that, OK, 3-billion-year-old basalts is fair enough, probably it can be sustained by this radioactive decay," says Alexander Nemchin, a geochemist at Curtin University in Perth, Australia, and one of the *Science* team's leaders. But 2 billion years is too young for current models, he says — "so now we've got a problem."

Nevertheless, the result is exactly what scientists hoped for when they chose the probe's landing site, says Brad Jolliff, a planetary scientist and mineralogist at Washington University in St. Louis and a co-author of the *Science*

The Chang'e 5 mission landed on the Moon Dec. 1, 2020, and lifted off 48 hours later with a stash of lunar rocks. CHINESE NATIONAL SPACE AGENCY'S (CNSA) LUNAR EXPLORATION AND SPACE ENGINEERING CENTER

A recovery crew secured the samples after the return capsule's touchdown on the grasslands of Inner Mongolia Dec. 16, 2020. CHINESE NATIONAL SPACE AGENCY'S (CNSA) LUNAR EXPLORATION AND SPACE ENGINEERING CENTER



RIGHT: Oceanus Procellarum is the only feature on the Moon to earn the designation of the Latin word for "ocean". At over 1,600 miles (2,500 km) across, it's vaster than the multitude of lunar maria, or "seas."

BELOW: Rifts outlining Oceanus Procellarum can been seen in gravitational anomalies (in blue) as measured by NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission. NASA/GSFC/ARIZONA STATE UNIVERSITY; NASA'S SCIENTIFIC VISUALIZATION STUDIO

The Chang'e 5 soil sample allocated to the Beijing SHRIMP Center weighs just 0.07 ounce (2 g), but with careful planning, researchers can extract a lot of information from it. BEIJING SHRIMP CENTER, INSTITUTE OF GEOLOGY, CAGS

study. "This actually shows that the main science goal was met — and that's pretty awesome."

Filling in the age gap

The age measurements of the samples were taken in two labs in Beijing. The *Nature* work was performed at the Institute of Geology and Geophysics at the Chinese Academy of Sciences; the sample published in *Science* was analyzed at the Beijing SHRIMP Center in collaboration with an international consortium. (A SHRIMP, or Sensitive High-Resolution Ion MicroProbe, is an instrument used for chemical analysis.)

Both teams used similar techniques: analyzing various isotopes of lead, which are produced by the decay of radioactive uranium and thorium. Since these processes happen at a predictable rate, measuring how much of each isotope existed relative to each other allowed the team to determine the age of the samples.

For some researchers, the most exciting part of the analysis isn't just learning the age of Chang'e 5's landing site — it's that these measurements will also help determine ages of many other regions of the Moon's surface. That's because the age of Oceanus Procellarum is key to improving a completely different technique for understanding the Moon's history: counting impact craters.

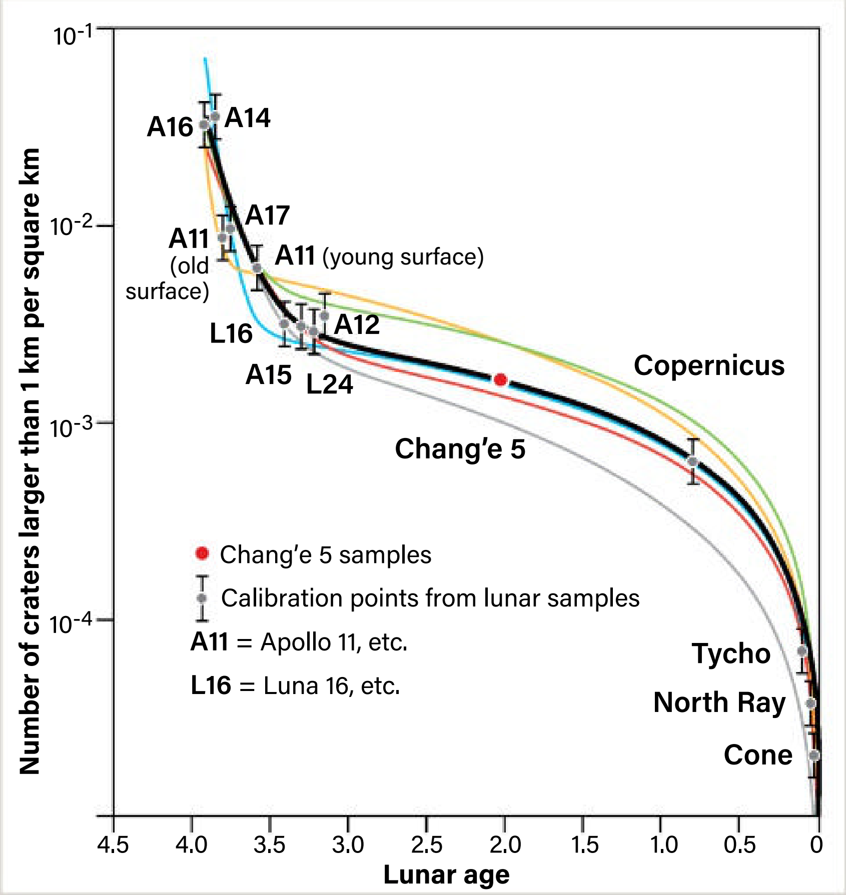
Generally, the more impact craters there are in a given area, the older that area is, as it's had more time to accumulate impacts. "We know that kind of in a relative way, and we've known that for many years," says Jolliff. "But to actually put numbers on that required samples."

To this point, the most accurate ages that existed were linked to rock samples 3 billion years or older from the Apollo and Luna missions. A handful of Apollo samples also allowed researchers to infer dates for some young impact craters formed within the past billion years.

But between 3 billion years ago and 1 billion years ago, "we just had this giant gap of 2 billion years — which is like half the age of the Moon," says Carolyn Crow, a planetary scientist at the University of Colorado in Boulder.

At 2 billion years old, the Chang'e 5 samples fall right in the middle of that gap, significantly improving the technique's calibration. "We're filling this gap, which is awesome," says Crow. "The ability to get some anchor in that time period is just so important."

And not just for the Moon: Counting craters is also how scientists estimate the ages of surfaces on bodies like Mars and Mercury. "They just have such big



ASTRONOMY: KELLIE JAEGER, AFTER LI ET AL. (2021)

THE CRATER-COUNTING CURVE

The number of locations on the Moon whose ages have been directly measured is so limited, they can all be identified on the graph at left. They come from the Apollo and Luna missions, which returned samples that revealed the age of their landing sites — all older than 3 billion years.

In addition, the missions returned fragments from young nearby craters, whose lab-measured ages yield the dates of those impacts. For instance, Apollo 12 landed on one of the rays of debris emanating from the crater Copernicus. The ejecta samples they brought back revealed Copernicus formed 800 million years ago.

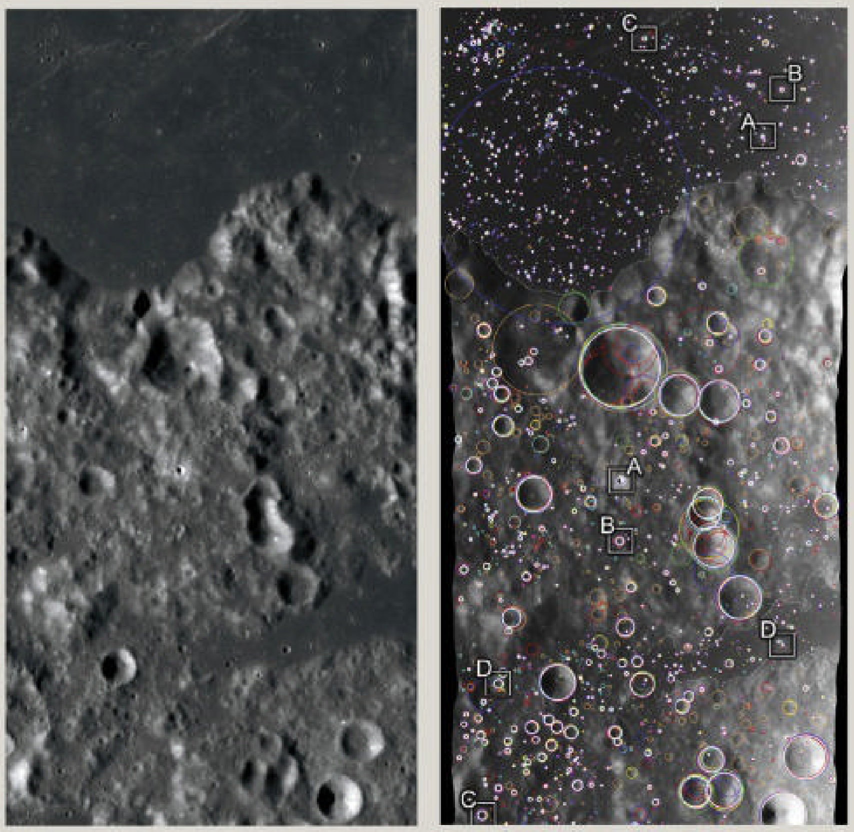
The thick ejecta blanket from such impacts erases or subdues existing craters, effectively "resetting" the apparent age of the surrounding surface. This means researchers can count the new craters that formed since the impact, obtaining another calibration point for the crater-counting chronology.

Similarly, Apollo 17 returned samples from the crater Tycho, Apollo 15 brought back ejecta from North Ray Crater, and Apollo 14 visited Cone Crater. All of those craters are younger than 1 billion years.

In this graph, the vertical axis is the density of craters in an area, given as the number of craters per square kilometer (0.39 square mile) that are larger than 1 kilometer (0.62 mile) in diameter. The array of lines represents the various crater chronology models that researchers have constructed in the last 20 years to fit these data points. The curve is the key to the technique: Researchers measure the crater density for a region of the Moon, then use a model curve to find the region's corresponding age along the horizontal axis.

While the models mostly agree at ages where there are data points, in the 2-billion-year gap in between, the technique is very uncertain: For a given density of craters, the variability in age given by the models is vast.

But Chang'e 5's landing site, at 2 billion years old, begins to fill this gap and narrow the range of models. The black line is the model that best fits the Chang'e 5 samples — very nearly a perfect match. While researchers will continue to refine their models and wait for even more data points, the Chang'e 5 samples provide a key anchor for the curve, improving confidence in the technique. *—M.Z.*



The older a surface is, the more craters of a given size it is likely to have. This is demonstrated clearly in this view of Mare Crisium and the rugged highlands bordering it to the south (left). In a 2014 study, several researchers and an algorithm identified craters in both regions (right). Based on the crater-counting method, the highlands are roughly 3.7 billion years old, whereas the mare surface is roughly 1.7 billion years old. ROBBINS ET AL. (2014)/ICARUS

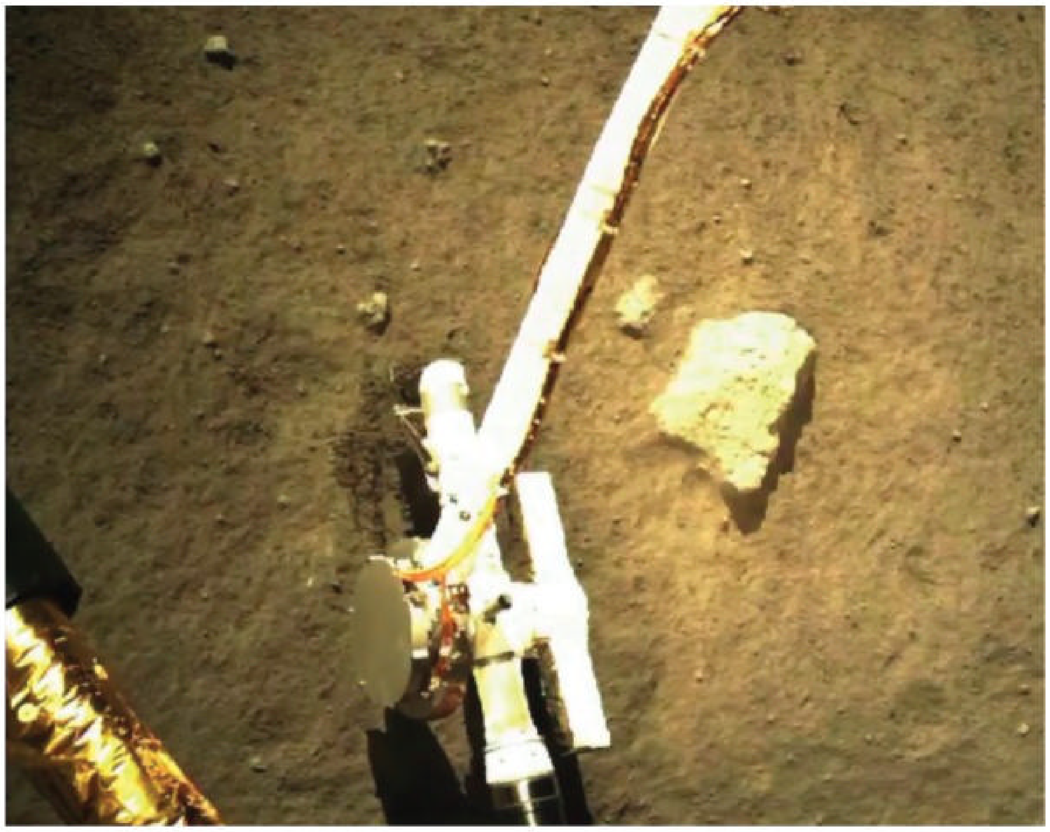
uncertainties on them and having at least one data point just helps constrain that so much better," says Crow.

Bringing the heat

While the results help clarify the crater-counting technique, our understanding of how magma could have been spewing from the Moon as recently as 2 billion years ago is murkier. That's because there's no clear source of heat.

The simplest explanation is that there are more radioactive minerals buried deep in the Moon than models predict. But the analyses reported in *Science* and one of the other *Nature* papers from a Chinese team give no indications that Chang'e 5's samples originally contained any more uranium or thorium than samples from the regions visited by Apollo and Luna.

In fact, according to the *Nature* paper, Chang'e 5's basalts have *less* of one type of radioactive material



ABOVE LEFT: It's possible that Chang'e 5's samples contain ejecta from Aristarchus Crater (seen here on Apollo 15), located some 370 miles (600 km) southeast of Chang'e 5's landing site. If researchers can identify fragments from Aristarchus, the crater's age could be determined in the lab — providing another calibration point for the crater-counting chronology. NASA

ABOVE RIGHT: Chang'e 5's sampling apparatus collected 3.8 pounds (1.7 kg) of lunar soil. CHINESE NATIONAL SPACE AGENCY'S (CNSA) LUNAR EXPLORATION AND SPACE ENGINEERING CENTER

found in previous lunar samples — a mixture called KREEP, made of potassium (K), rare Earth elements (REE), and phosphorus (P). "According to the previous theory, the KREEP-like components would provide heat to sustain the longevity of young magma," said Li Chunlai, study co-author and a researcher at the National Astronomical Observatories of the Chinese Academy of Sciences, in a statement. If that's not the case, "we should rethink the mechanisms" that are involved.

One possibility is that the Moon's interior consists of different minerals than scientists thought and can melt at lower temperatures, says Nemchin.

But there are alternative hypotheses — like tidal heating. Perhaps when the Moon was younger and orbited closer to the Earth, the tidal force of our planet's gravity stretched and deformed the Moon, heating it enough to keep it molten. To test either scenario will require more sample analysis and detailed modeling.

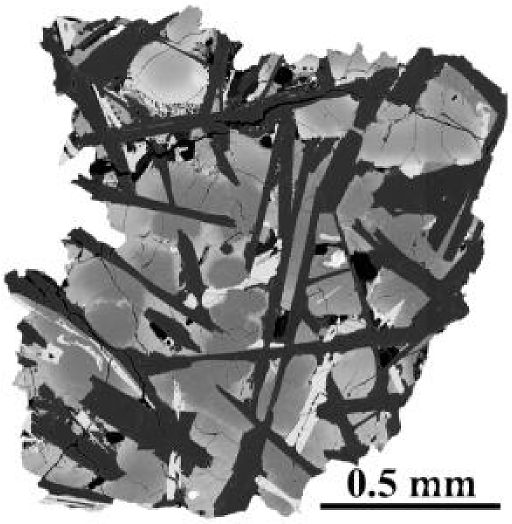
Scientists hope to glean many more insights from the Chang'e 5 samples and eventually reconstruct their history in detail.

The third *Nature* paper opened another line of investigation into Chang'e 5's lunar loot by measuring the water content of basalt samples. Analysis of grains of apatite, a phosphate mineral, found they were no more than 0.03 percent water, indicating the Moon's mantle is very dry.

This gives scientists some insight into the Moon's formation. In the currently favored giant-impact theory, Earth collided with another small planet, creating a hot debris disk out of which the Moon eventually coalesced. "One of the big constraints on that process — how that works, or if it was something else entirely — is how much water you have in the mantle," says Crow. "If there's a big debris disk, and it's really hot, you're going to get rid of all your water."

Scientists hope to glean many more insights from the Chang'e 5 samples and eventually reconstruct their history in detail. Lead dating is just one technique to apply to a rock — "there's a whole other suite of them, and they all give different kinds of information," says Crow. "When did it form? When was it last heated? … When was the last time it saw a giant impact? When was it excavated and put on the surface?"

Those analyses often require destroying the samples to some extent, like melting them in acid or heating them with lasers and measuring the noble gases they release. So, because the amount of Chang'e 5 material is so limited — the Beijing SHRIMP center was granted just 0.07 ounce (2 grams) of soil — researchers are meticulously planning their analyses to get the most out of the material, saving the most



As magma cools and solidifies, it forms irregular crystalline patterns, as seen in this scanning electron microscope image of a lunar basalt fragment used in the *Science* study. BEIJING SHRIMP CENTER, INSTITUTE OF GEOLOGY, CAGS

destructive techniques for last. “I want to melt them with laser beams,” Crow says with a laugh.

Lunar return

Researchers had to wait 44 years between receiving samples from Luna 24 and from Chang’e 5. They won’t have to wait nearly as long for the next haul: Chang’e 6, which was built as a backup to Chang’e 5, is scheduled to launch in 2024. Then, perhaps as early as 2025, NASA intends to return astronauts to the Moon with the Artemis program, which will be able to return many more samples than a robotic mission.

This coming second era of lunar sample return could help scientists pin down the dates of many of the Moon’s largest and oldest impact craters, known as impact basins. Only one basin has been directly sampled and its age measured: Imbrium on the Moon’s nearside, at 3.9 billion years old. Getting samples from others could help clarify the early history of not just the Moon, but the entire solar system.

For instance, NASA is hoping to land Artemis missions at the lunar south pole. There, astronauts should be able to collect samples from the mysterious South Pole-Aitken (SPA) basin. The oldest and largest of the Moon’s basins, it stretches from the South Pole roughly 1,550 miles (2,500 kilometers) into the lunar farside. Data taken from orbit suggest the SPA basin has a composition that doesn’t match any previous lunar samples.

Samples from the SPA and other basins around the Moon will tell researchers if they all formed at the same time — during the solar system’s chaotic early period known as the Late Heavy Bombardment — or if they were spaced out over a longer duration. “It would be great to go to the farside,” says Crow. “If you get away from Imbrium, you can try and get other material.”

One thing is certain: The Chang’e 5 samples are likely to ignite a new wave of interest in the Moon’s early history to explain its late volcanism.

“When it’s just a suggestion, everybody tends to ignore it,” says Nemchin. “Yes, we suspected that younger basalts are on the Moon, but it wasn’t on the forefront of everybody’s thinking. Right now, it’s probably gonna be.”

Mark Zastrow *is senior editor of* Astronomy.

Copernicus Crater (near the Moon’s limb) is one of the most prominent craters on the near side of the Moon. This shot was taken from lunar orbit during the Apollo 12 mission, which sampled the crater’s ejecta. NASA

Check out these classic sky guides

Modern tech has made stargazing more accessible, but nothing beats an old-school observing guide. **BY RAYMOND SHUBINSKI**

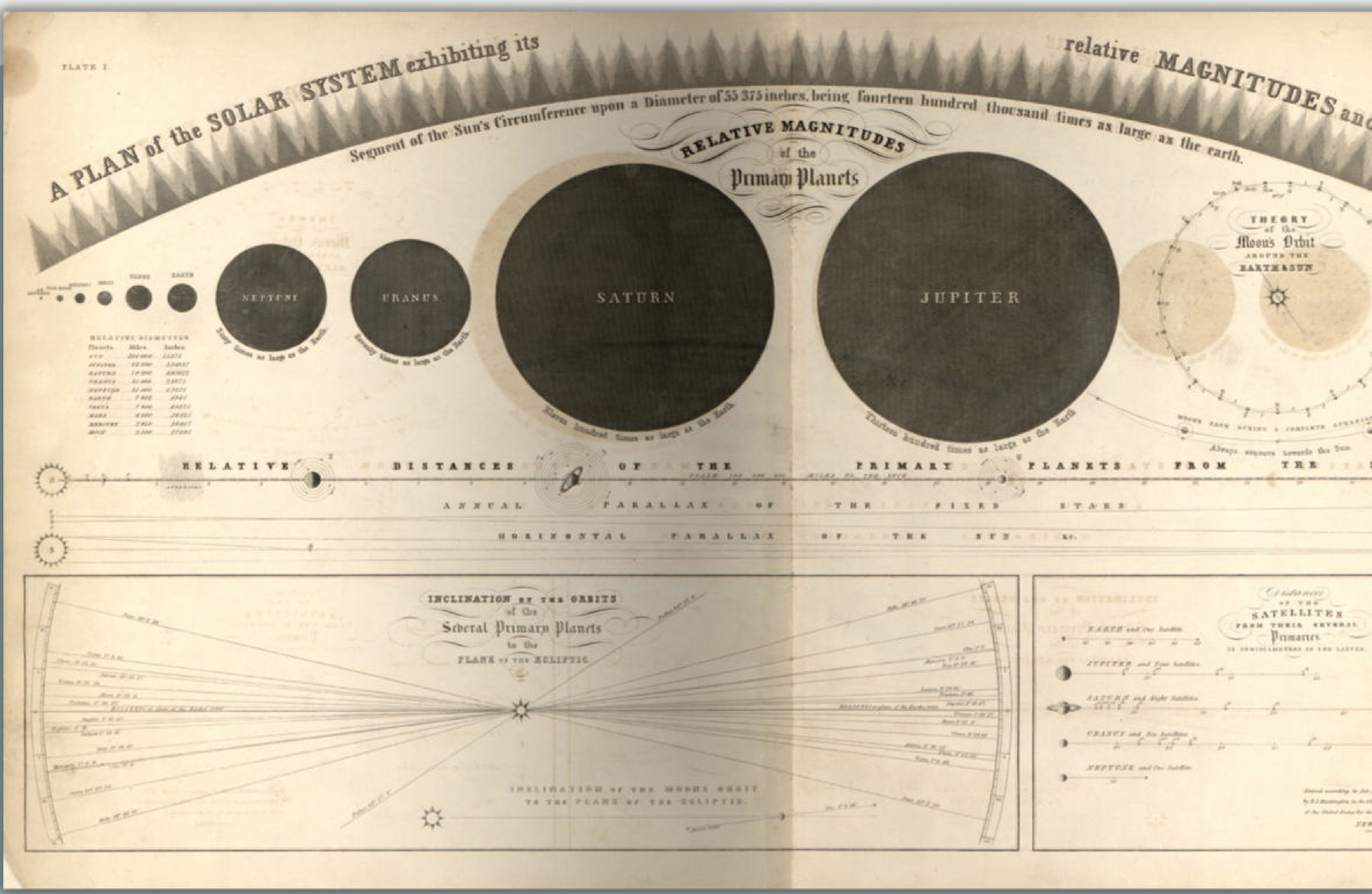


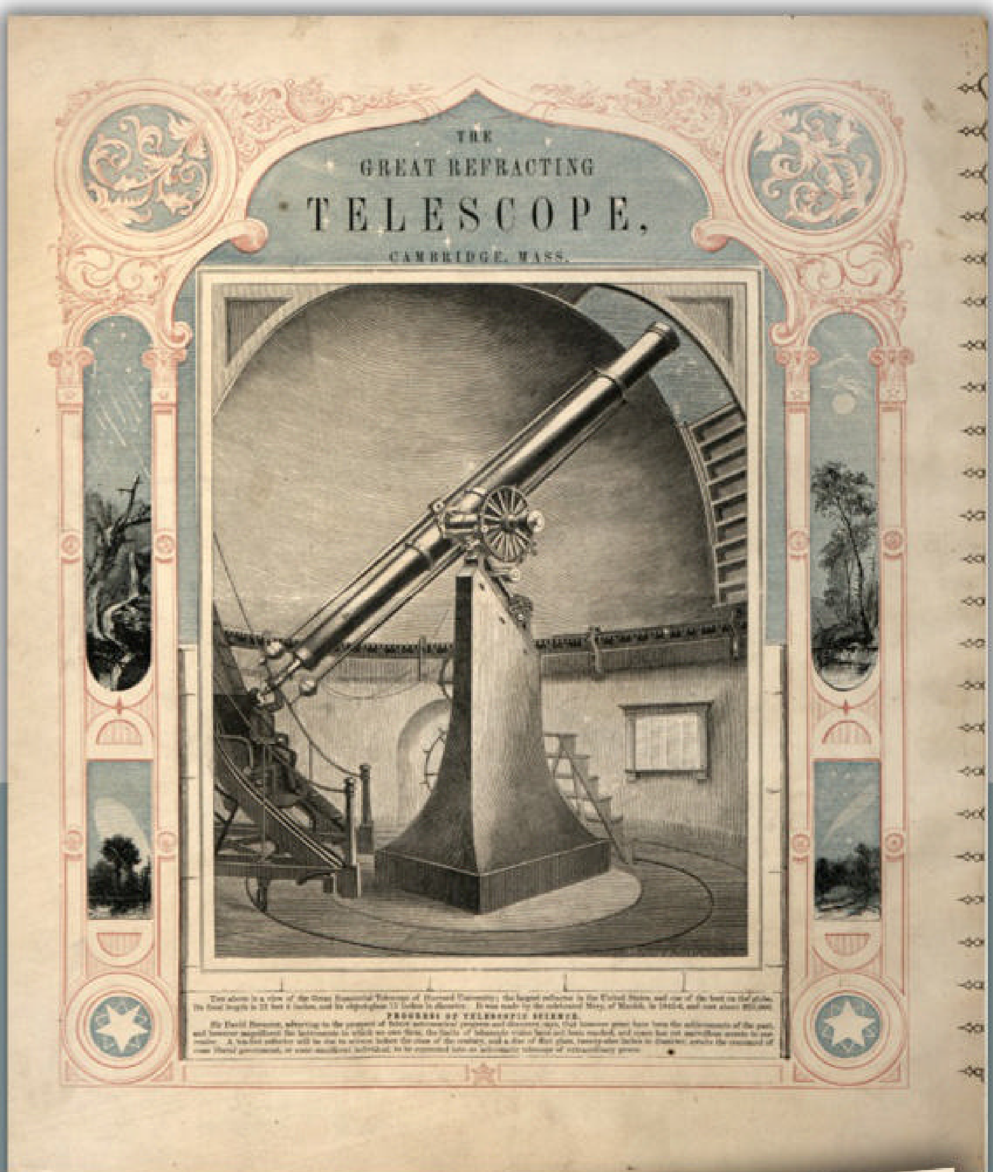
PLATE I.
A PLAN of the SOLAR SYSTEM exhibiting its relative MAGNITUDES and
Segment of the Sun's Circumference upon a Diameter of 55 375 inches, being fourteen hundred thousand times as large as the earth.
RELATIVE MAGNITUDES of the Primary Planets
NEPTUNE
URANUS
SATURN
JUPITER
Sixty times as large as the Earth
Seventy times as large as the Earth
Eleven hundred times as large as the Earth
Thirteen hundred times as large as the Earth
THEORY of the Moons Orbit AROUND THE EARTH & SUN
RELATIVE DISTANCES OF THE PRIMARY PLANETS FROM THE SUN
ANNUAL PARALLAX OF THE FIXED STARS
HORIZONTAL PARALLAX OF THE SUN &c.
INCLINATION of the ORBITS of the Several Primary Planets to the PLANE of the ECLIPTIC
INCLINATION of the MOONS ORBIT TO THE PLANE OF THE ECLIPTIC
Distances of the SATELLITES FROM THEIR SEVERAL Primaries
EARTH and the Satellite
JUPITER and four Satellites
SATURN and Eight Satellites
URANUS and Six Satellites
NEPTUNE and One Satellite

ASTRONOMY ENTHUSIASTS today have an astounding array of observing aids available at their fingertips. From computer simulations to phone and tablet apps, some may say there is little need for paper maps or guidebooks to the cosmos.

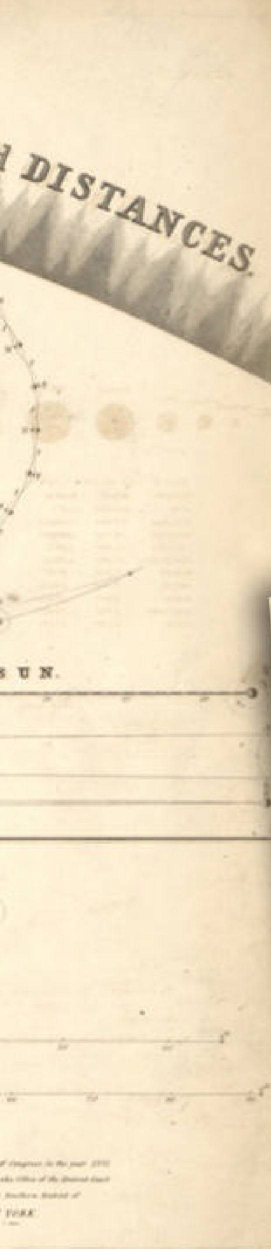
Yet there is something satisfying and tactile about thumbing through a classic observing guide in preparation for a night under the stars. Exploring some of these resources, past and present, can be enjoyable and useful even in the digital age.

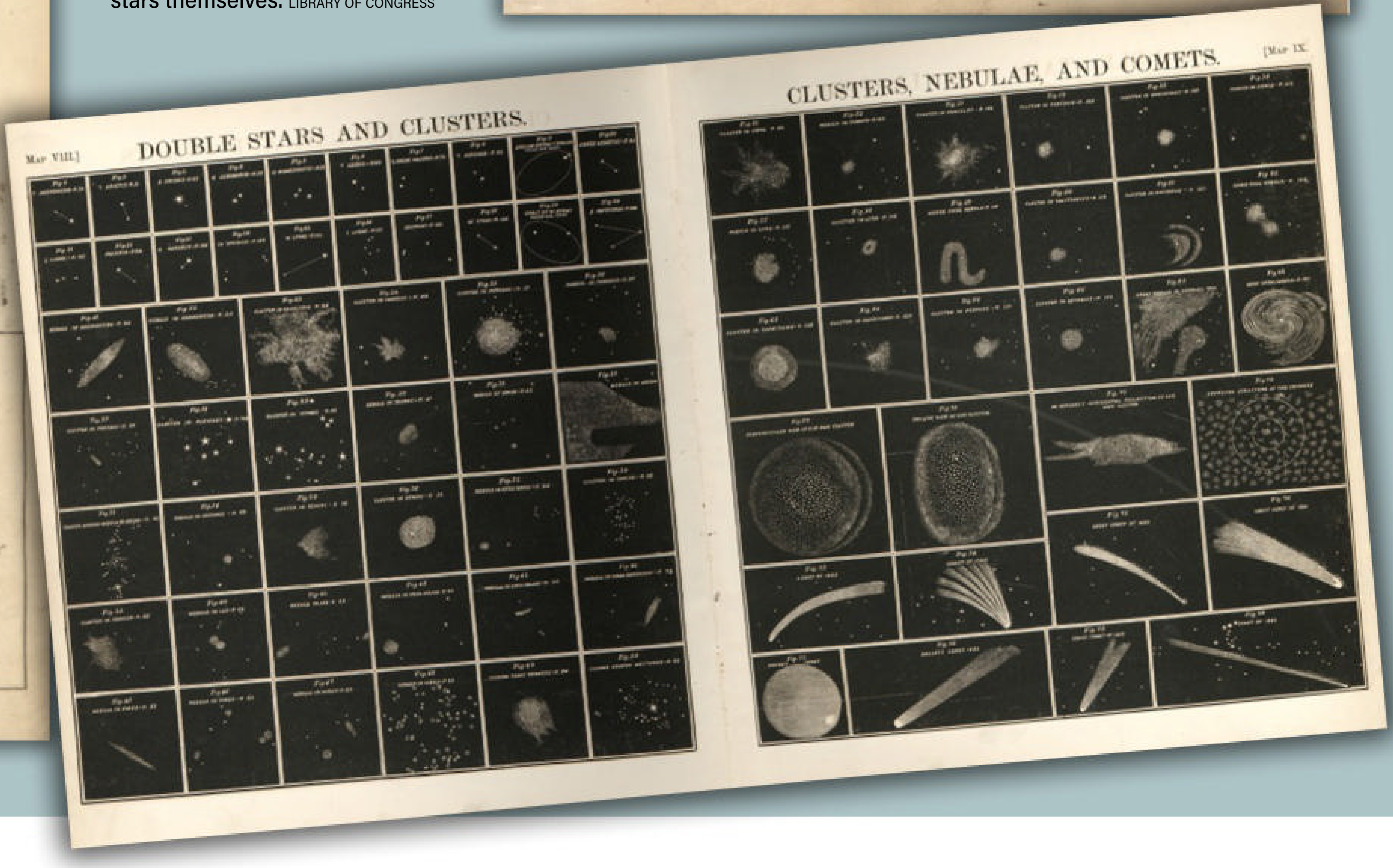
Geography of the Heavens

Little information is available on the life of the author of one of astronomy's predominant classical observing guides. Elijah Burritt was a teacher who likely saw a need for better textbooks for observers. First published in 1833, the six maps of his atlas and accompanying guidebook, *Geography of the Heavens*, fulfilled this need, selling more than 300,000 copies. Some 200 years after first going to press, his maps are still being reproduced and sold.

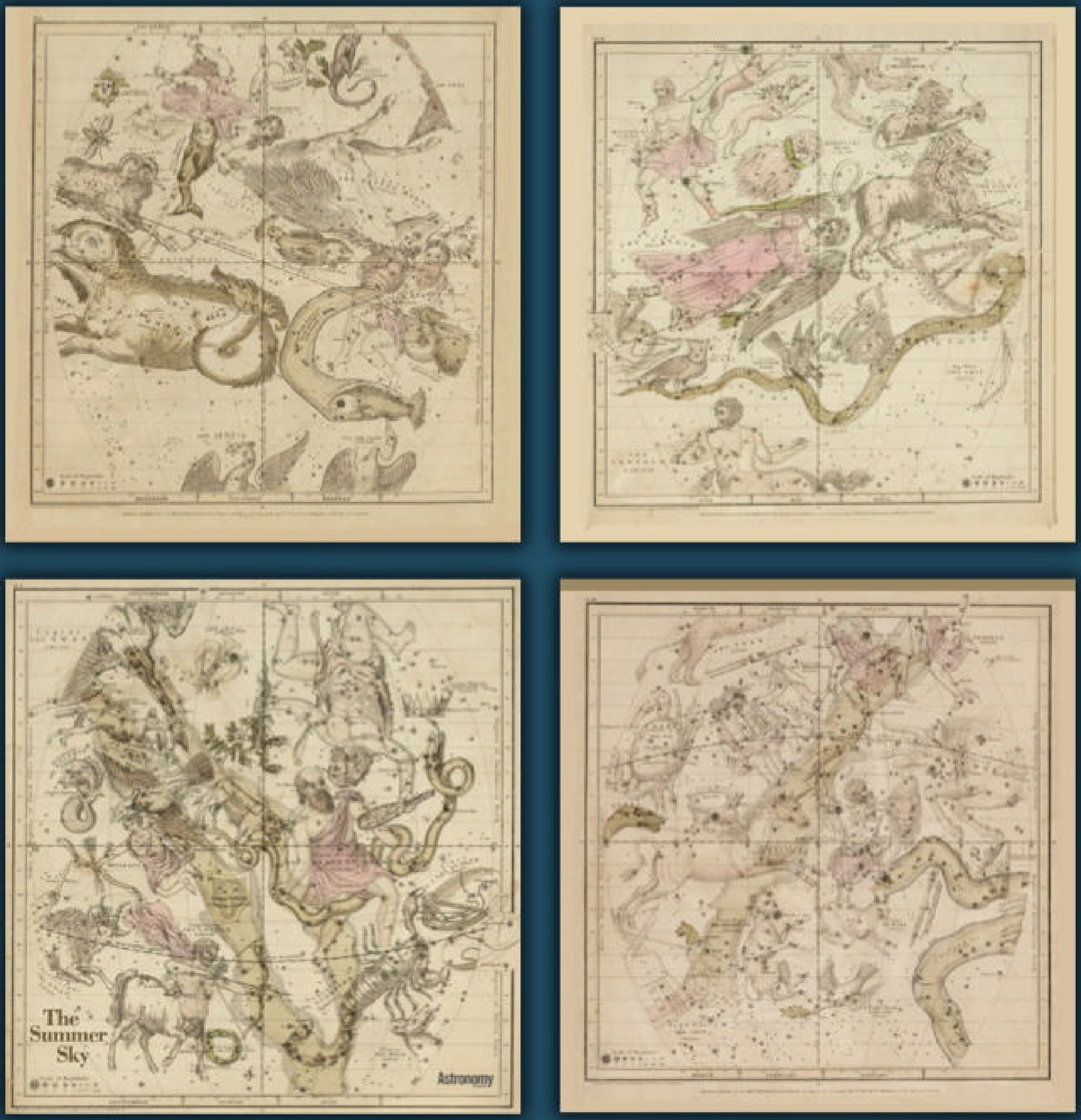


Geography of the Heavens
First published in 1833, Elijah Burritt's *Geography of the Heavens* changed the landscape of astronomy guidebooks. Approaching the topic with more value placed on observation over theory, Burritt encouraged readers to get out under the stars themselves. LIBRARY OF CONGRESS





JLDELAWTER/DREAMSTIME



Geography of the Heavens Burritt's guidebook introduced readers to (clockwise from top left) the fall, spring, winter, and summer constellations. At the end of the book, Burritt shows off the stars and constellations around the South (below left) and North (below right) Celestial Poles. LIBRARY OF CONGRESS

THE CONSTELLATIONS
THE CONSTELLATIONS

The Wonders of the Telescope

Observing guides truly blossomed in the 19th century. Telescopes were becoming more affordable and the study of astronomy had taken on an allure beyond its use for navigation and almanacs. *The Wonders of the Telescope*, published in 1805, promises "a display of the wonders of the heavens and of the system of the universe." It has all you need to explore the night sky. There are maps and fold-out charts, along with detailed descriptions of the Sun, Moon, planets, and even a few deep-sky objects. This little book helped set the standard form for the next 200 years of observing guides.

NOTABLE MENTIONS

Defining what makes a guide a classic can be difficult, and there are plenty of other books potentially deserving of that title. Some additional selections are:

- *The Peterson Field Guide to the Stars and Planets*, by Donald Menzel
- *The Constellations*, by Lloyd Motz and Carol Nathanson
- *The Cambridge Guide to the Constellations,* by Michael E. Bakich

Of opera-glasses and telescopes

When I was about 10 years old, I found a battered copy of *Astronomy With an Opera-Glass*, by Garrett P. Serviss, high up on a shelf in our town's old Carnegie library. I later discovered that Serviss had written a series of astronomy books, including three others that are observing guides. At the end of the 19th century, he began his Urania Lectures — an early multimedia event. With backing from Andrew Carnegie, Serviss took the show on the road, popularizing astronomy and science for the masses.

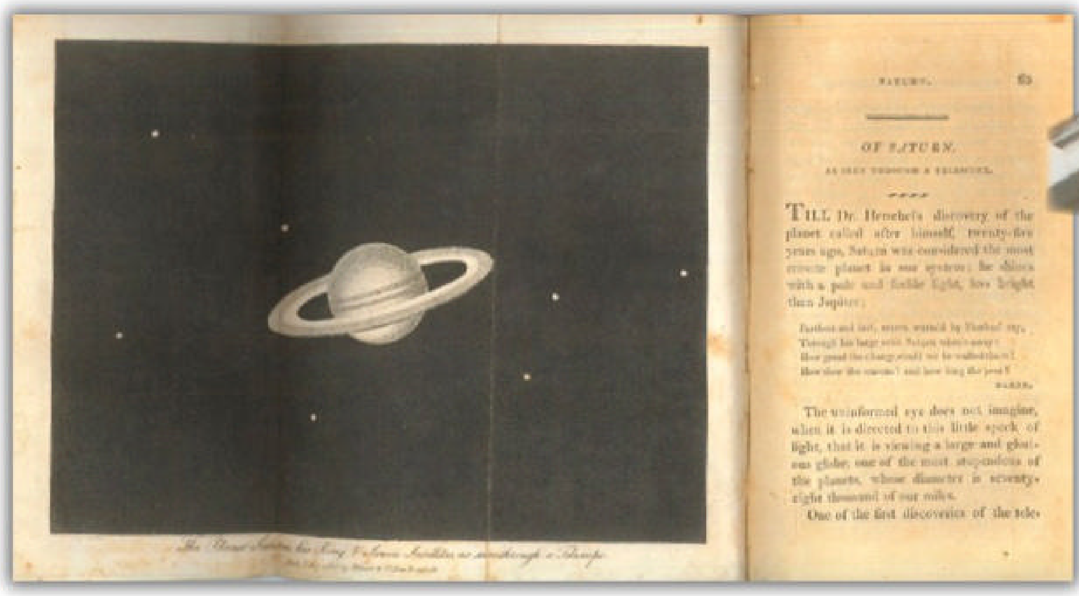
When he settled down, he wrote books on all aspects of astronomy, science fiction, and even relativity. In addition to with *Astronomy With an Opera-Glass*, he also wrote *Pleasures of the Telescope*. His style is delightfully illustrative of attitudes in the 19th century and wonderfully informative. One of my favorite quotes from his writing, "But let us sit here in the star light, for the night is balmy, and talk about Arcturus," shows how he is truly at ease with the sky. Some of the information is dated, but you can certainly learn your way around the sky with these delightful books. And both books feature star charts that are still useful. I have had my own copies of these books for years. The star maps and descriptions of celestial wonders are fascinating, and I continue to use these guides for observing.

Norton's Star Atlas

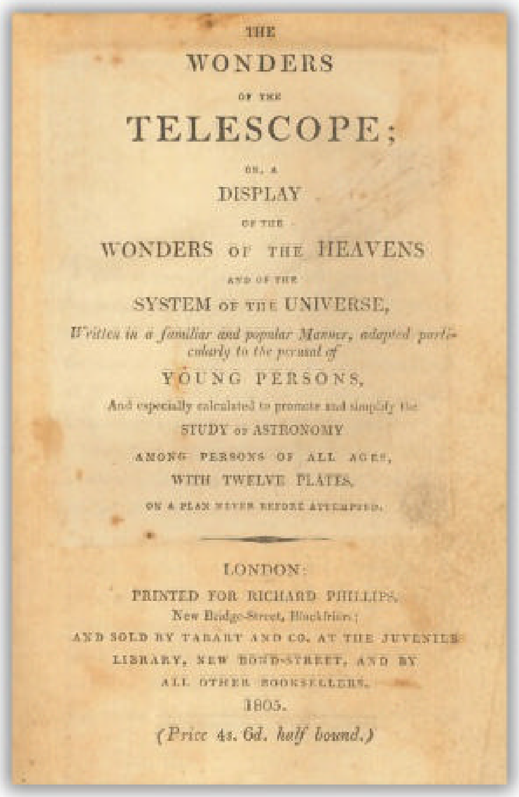
For many 20th-century astronomy enthusiasts, amateur or professional, one guidebook defines the era: *Norton's Star Atlas*. The *Atlas* first appeared in 1910 — the same year its creator, Arthur Philip Norton, became a member of the British Astronomical Association. Born in 1876, he was as a young man given an old family telescope, which sparked a lifelong interest in astronomy and science. Norton spent his career as a schoolmaster teaching science and pursuing his love of the sky as an amateur. His guidebook has become a touchstone for observers.

The original 1910 guidebook was called *The Star Atlas and Reference Book*. It was so popular that a second edition was published during World War I, even though there was a national paper shortage in Britain. By the 1921 third edition, the familiar star charts and reference layout were well established. An interesting feature of the main star maps is Norton's use of gores: If sections of a globe are cut off into individual maps, they look like truncated ovals. By using this method, Norton was able to avoid some of the distortions that occur with other map projections.

Over the years, *Norton's Star Atlas* has evolved. The *Atlas* has always had notes on astronomical terms, planets, stars, nebulae, and more. With each edition, these sections have been updated and enlarged. The star maps have also been



RAYMOND SHUBINSKI



THE
WONDERS
OF THE
TELESCOPE;
OR, A
DISPLAY
OF THE
WONDERS OF THE HEAVENS
AND OF THE
SYSTEM OF THE UNIVERSE,
Written in a familiar and popular Manner, adapted particularly to the perusal of
YOUNG PERSONS,
And especially calculated to promote and simplify the
STUDY OF ASTRONOMY
AMONG PERSONS OF ALL AGES,
WITH TWELVE PLATES,
ON A PLAN NEVER BEFORE ATTEMPTED.

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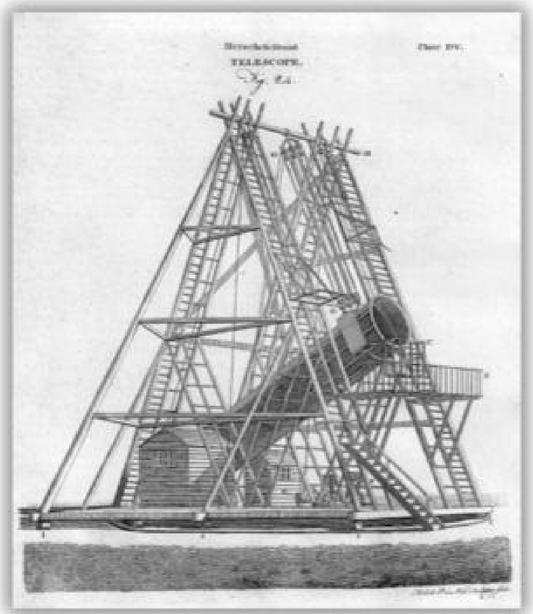
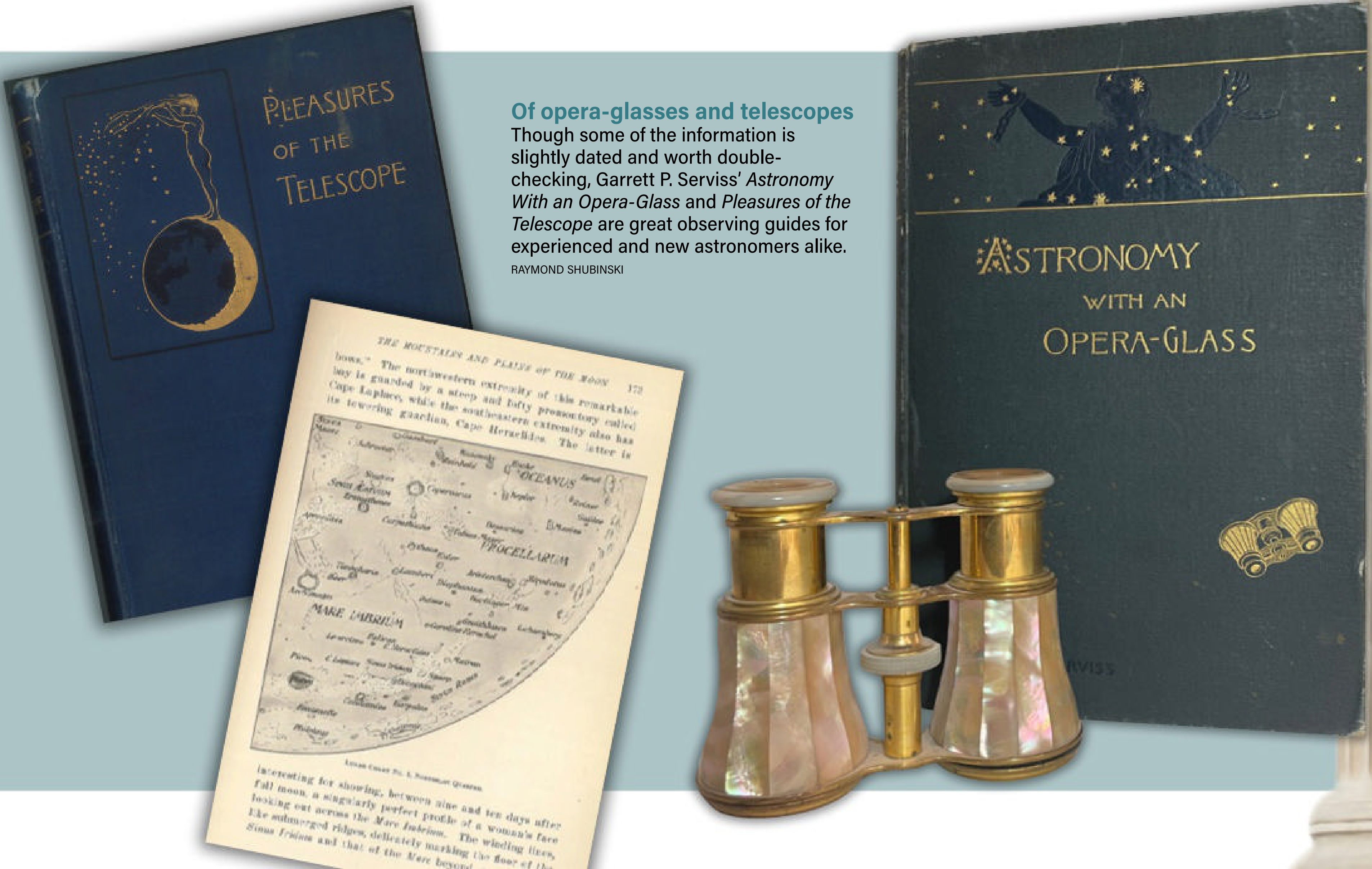
RAYMOND SHUBINSKI

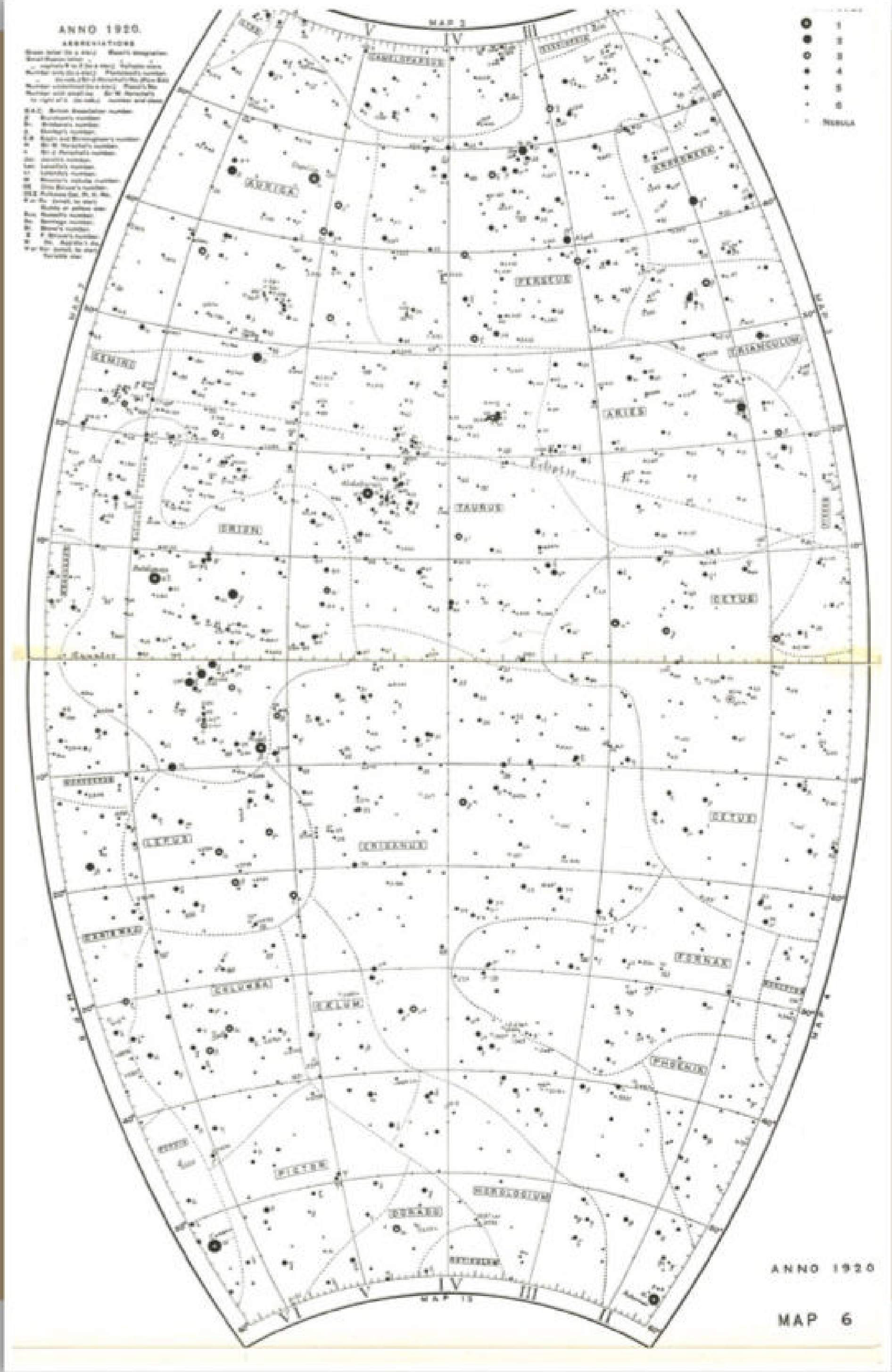


WIKIMEDIA COMMONS

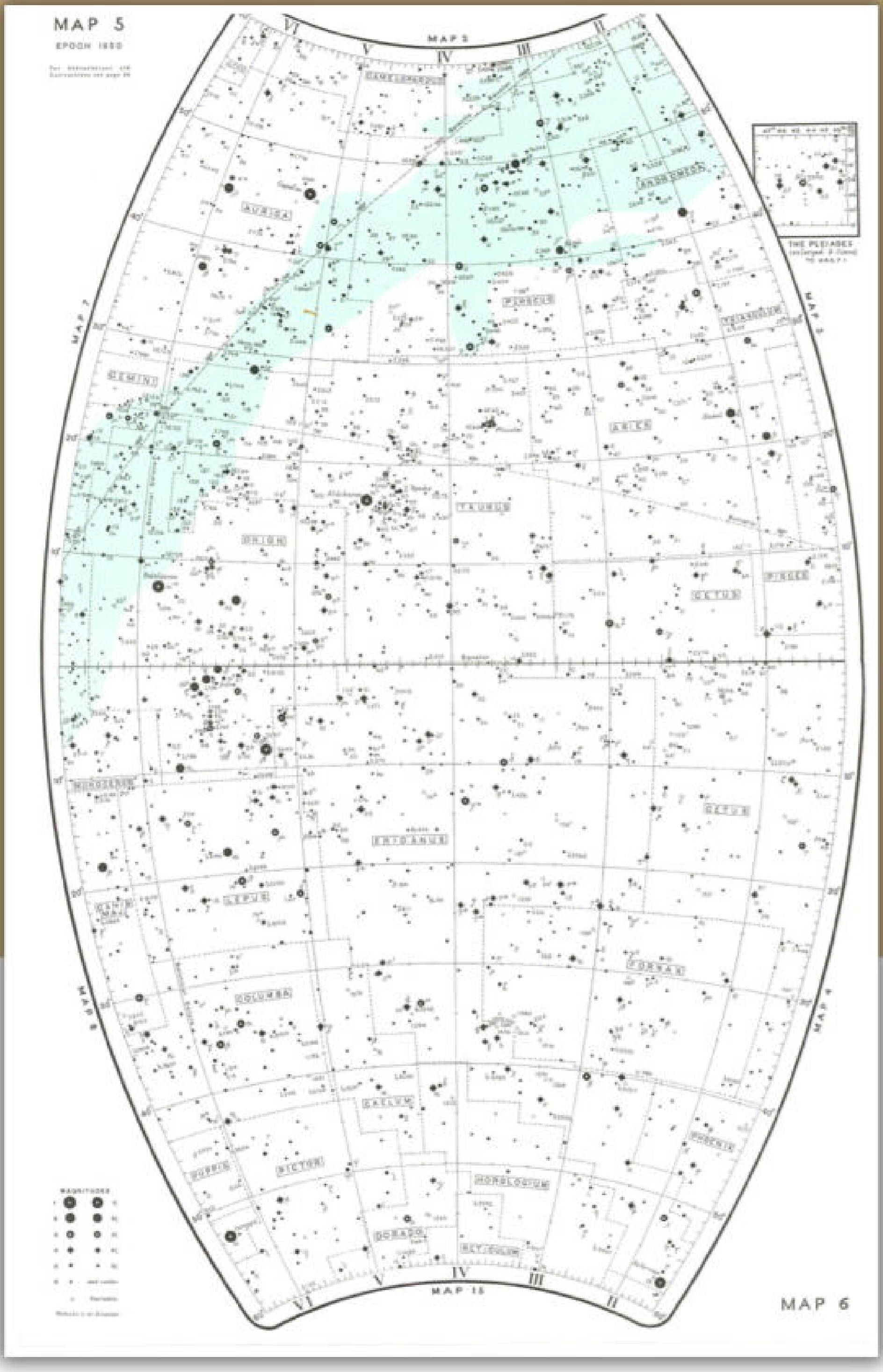
The Wonders of the Telescope
With fold-out charts and maps, this book has everything an observer needs. An illustration of William Herschel's 49-inch telescope (right) also appears in its pages.



Of opera-glasses and telescopes
Though some of the information is slightly dated and worth double-checking, Garrett P. Serviss' *Astronomy With an Opera-Glass* and *Pleasures of the Telescope* are great observing guides for experienced and new astronomers alike.
RAYMOND SHUBINSKI



Norton's Star Atlas Arthur Philip Norton's *Star Atlas* defined 20th-century observing for many astronomers. This famous guidebook features notes on astronomical terms, planets, stars, nebulae, and more, which have been updated with each new edition published. RAYMOND SHUBINSKI



CLASSICS FOR KIDS

I have a soft spot for a few guidebooks from when I was a kid. Here are some of my favorites:

- *Find the Constellations,* by H.A. Rey
- *The Stars: A New Way to See Them,* by H.A. Rey
- Golden Nature Guide's *Stars,* by Herbert Zim and Robert Baker
- *The Observer's Book of Astronomy,* by Patrick Moore

updated for the changing star coordinates caused by precession. The most noticeable change in the *Atlas* occurred in 1933. Before 1930, constellation boundaries had not been formalized. Constellations and their stars appeared contained by random wavy lines on sky maps. There was some agreement as to what stars belonged to each constellation, but there were also possible variations, depending on who was making the maps. The first four editions of the *Atlas* have the old-style boundaries. In 1930, the International Astronomical Union formalized constellation outlines by following lines of right ascension and declination to set the boundaries. Norton brought his maps into the new era for the fifth edition by using these precise boundaries. After more than 100 years and 20 editions later, this beloved observing guide is still a valuable aid to many observers. I imagine that Norton would certainly be pleased and perhaps a little surprised.

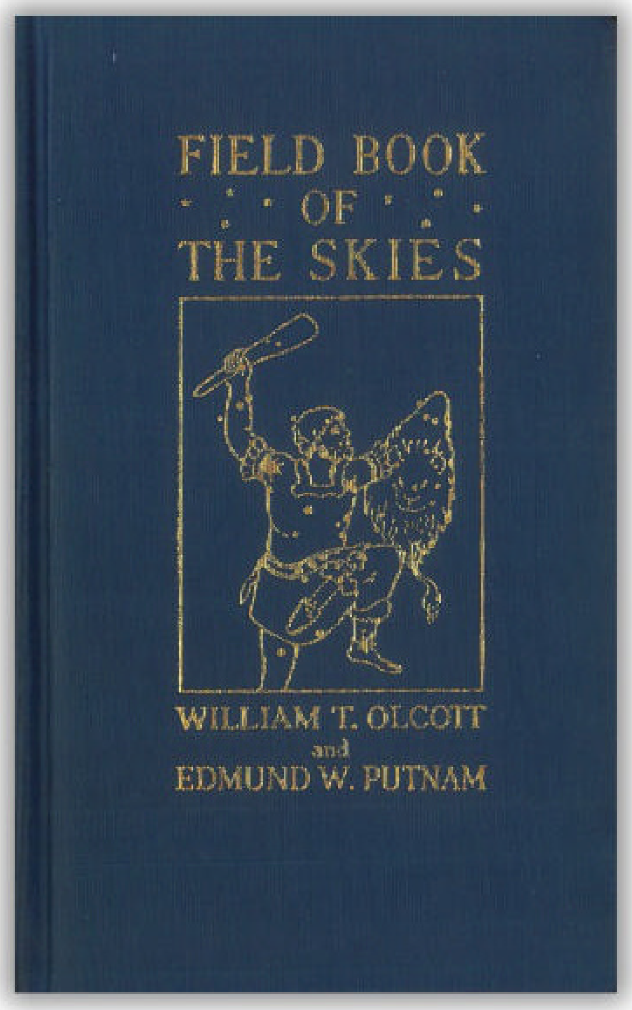
Field Book of the Skies

The *Field Book of the Skies*, by William T. Olcott, was published in 1929 and quickly found a following among stargazers. Olcott arranged his guide by season. The charts are simple and do not have coordinate references. Each constellation section gives location and mythology information. Olcott describes what can be seen with the unaided eye and field glasses, all with an accompanying chart. Then, he provides a page with objects for telescopes and an expanded chart to find them. The book also has information for beginners, a section on the planets, and basic charts of the Moon

The Gutenberg Project is working to digitize and archive thousands of out-of-print books with expired copyrights. There are many 19th-century astronomy books available through this website that would otherwise be difficult or expensive to find. You can find the project at: **www.gutenberg.org.**

during various phases. It's this layout that proved so popular with the public.

Olcott originally intended to become a lawyer, but then he fell in love with a young woman named Clara Hyde. She introduced him to stargazing, which set him on a path of observing and publishing. Olcott was fascinated with the mythology of the sky and published several books on the subject. He was a founding member of the American Association of Variable Star Observers (AAVSO). In the 1950s, AAVSO director Margaret Mayall and her husband Robert oversaw the fourth edition of the *Field Book*, which remained in print for another two decades. Touchingly, Olcott dedicated the *Field Book of the Skies* to his wife Clara.



Field Book of the Skies William T. Olcott published *Field Book of the Skies* in 1929 after his future wife, Clara Hyde, introduced him to the night sky. Within its pages are sections on the planets, constellations, and Moon phases. RAYMOND SHUBINSKI

Exploring with binoculars

Scanning the stars with binoculars is a wonderful way to relax on a clear night. *Exploring the Night Sky With Binoculars,* by Patrick Moore, published in 1996, has earned a place among the classics for observers with low-power instruments. Moore was the ultimate amateur astronomer. He never received a degree in astronomy but turned his interest and intellect into a lifelong career. Moore's book for binocular stargazing is straightforward and easy to use — a hallmark of a classic. The constellations are presented in alphabetical order, but the charts are reminiscent of Olcott's *Field Book of the Skies*. Moore is a master at clarity in providing guidance to the wonders of each constellation. After four editions, this is still an outstanding guidebook.

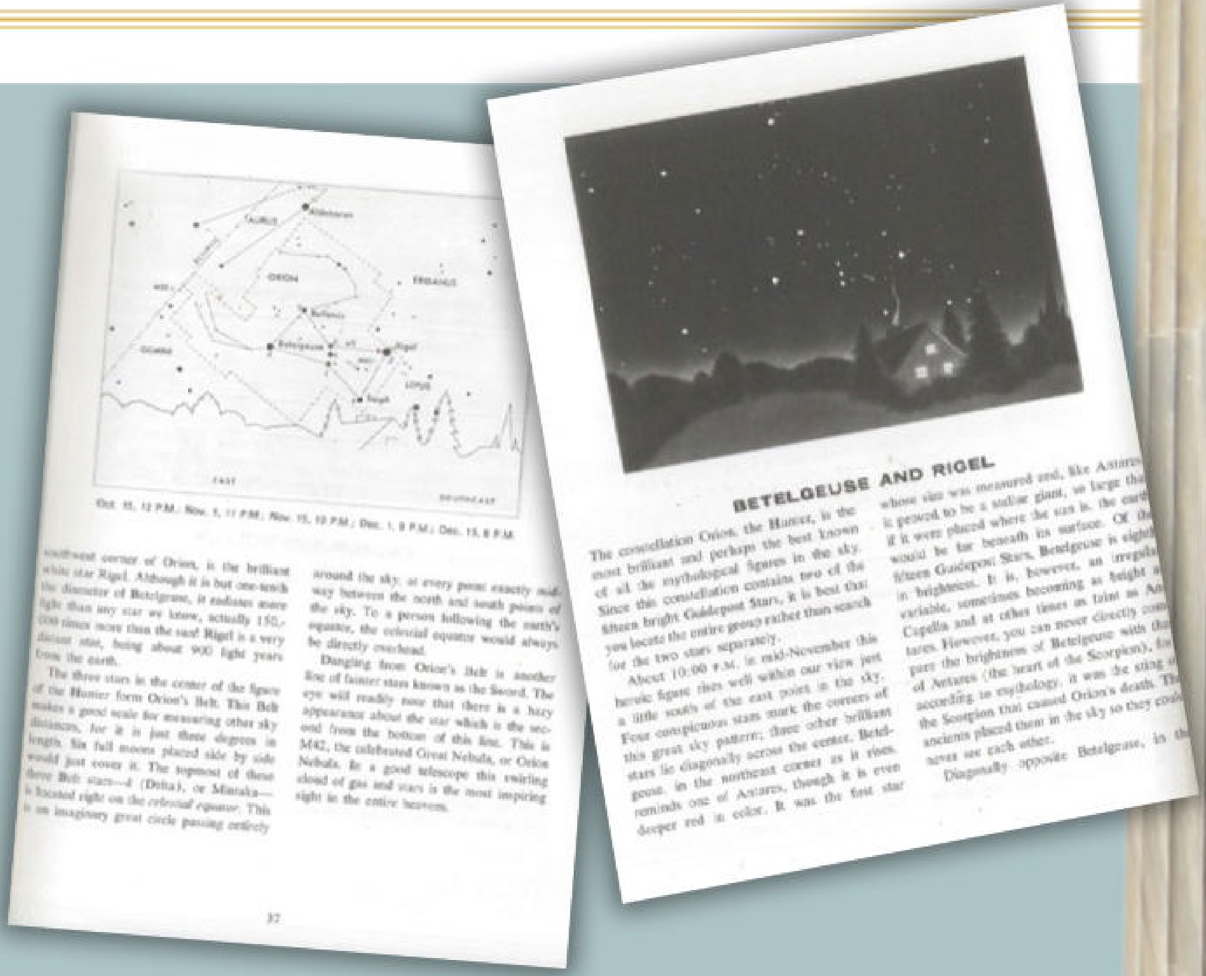
Guideposts to the Stars

Howard Shapley described our next author as "the world's greatest non-professional astronomer." True to Shapley's description, Leslie Peltier discovered Nova Herculis 1963 as well as a few other comets and novae. Published in 1972, Peltier's *Guideposts to the Stars: Exploring the Skies Throughout the Year* provides easy reading to prepare for a night's observing. One of the book's delights are the drawings and charts that accompany the descriptions of how to find stars and constellations. On each two-page spread is a drawing of the sky that shows the horizon and a house for scale. On the facing page is a chart of the same area, giving details of what can be seen. This sense of scale helps steer the observer on their journey.

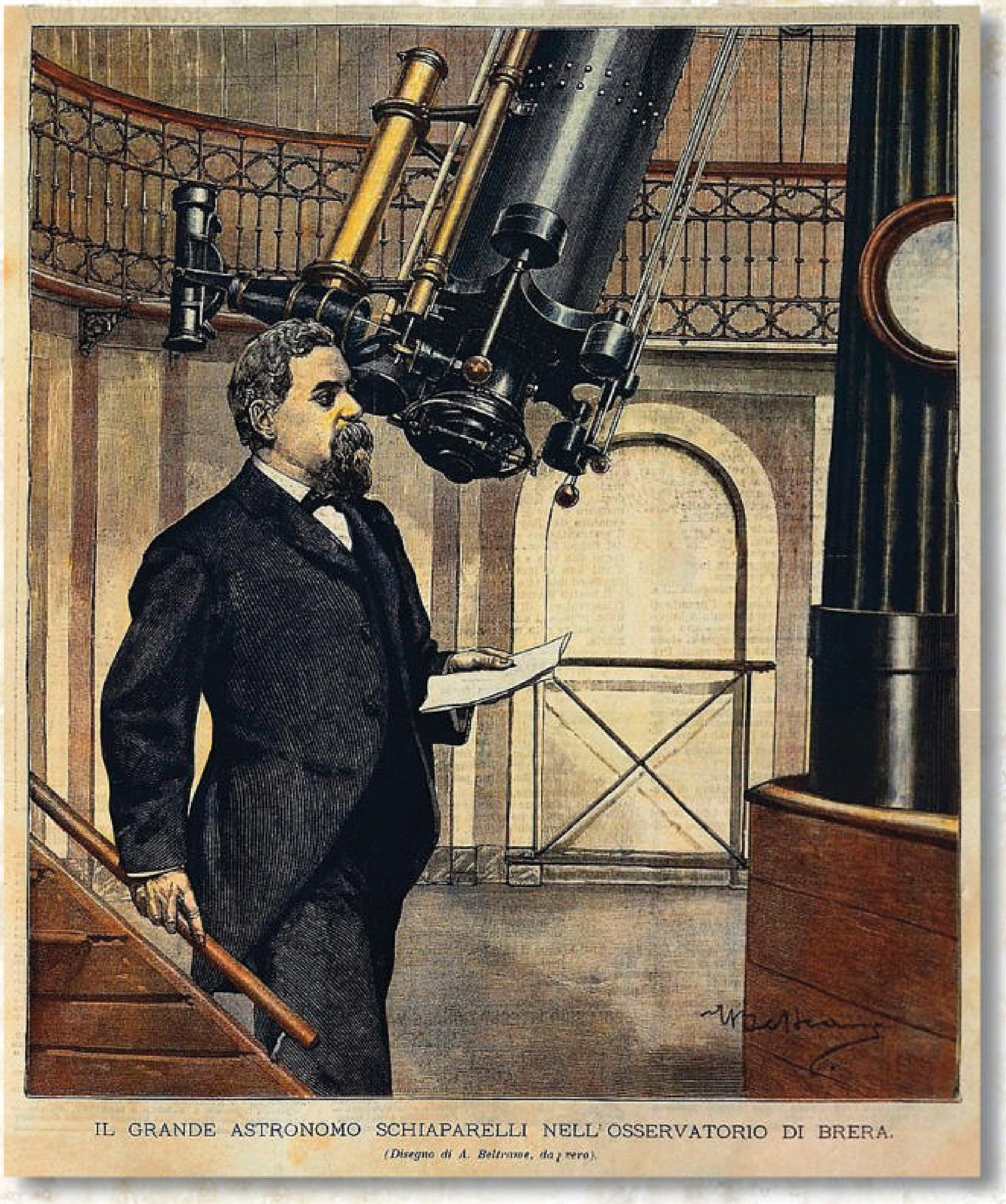
Precious pages

What makes an observing guide a classic can be quite subjective. No one book is going to cover every topic or area you may need for a night's observing. If you have been watching the sky throughout your life as I have, though, there are a few books you will always want on your shelf to plan your next evening under the stars.

Raymond Shubinski *is a contributing editor who loves to observe with a guidebook and binoculars in hand under a dark sky.*



Guideposts to the Stars One of this book's delights are the drawings of what one sees when looking at the night sky paired with a detailed chart on the next page, perfectly preparing readers for a night of observing. RAYMOND SHUBINSKI


IL GRANDE ASTRONOMO SCHIAPARELLI NELL'OSSERVATORIO DI BRERA.
(Disegno di A. Beltrame, dal vero).

Giovanni Schiaparelli didn't just see canals on Mars. He also recorded odd markings on Mercury.

BY WILLIAM SHEEHAN

Only intermittently visible in the twilight before sunrise or after sunset, Mercury is the smallest and least conspicuous of the naked-eye planets. However, its surface is the second easiest (after Mars) to examine with a telescope. Named for the swift-footed messenger of the gods of Olympus, diminutive Mercury has recently attracted outsize attention. On Oct. 1, 2021, the joint European-Japanese BepiColombo spacecraft made its first of six flybys of the tiny planet before it settles into orbit around Mercury in 2025.

The future of Mercury exploration is surely bright. But for a long time, we knew very little about the planet. And what little we did know was mostly wrong.

Some 140 years ago, Italian astronomer Giovanni Virginio Schiaparelli launched an investigation of Mercury that still stands as one of the most heroic endeavors of the visual telescopic era. That valiant effort deserves remembrance this April, as the planet swings to its most favorable evening elongation of the year — once more garnering the attention of those seeking a unique observing challenge. And, as an added bonus, Mercury offers another pleasant surprise this time around. (But more on that later.)

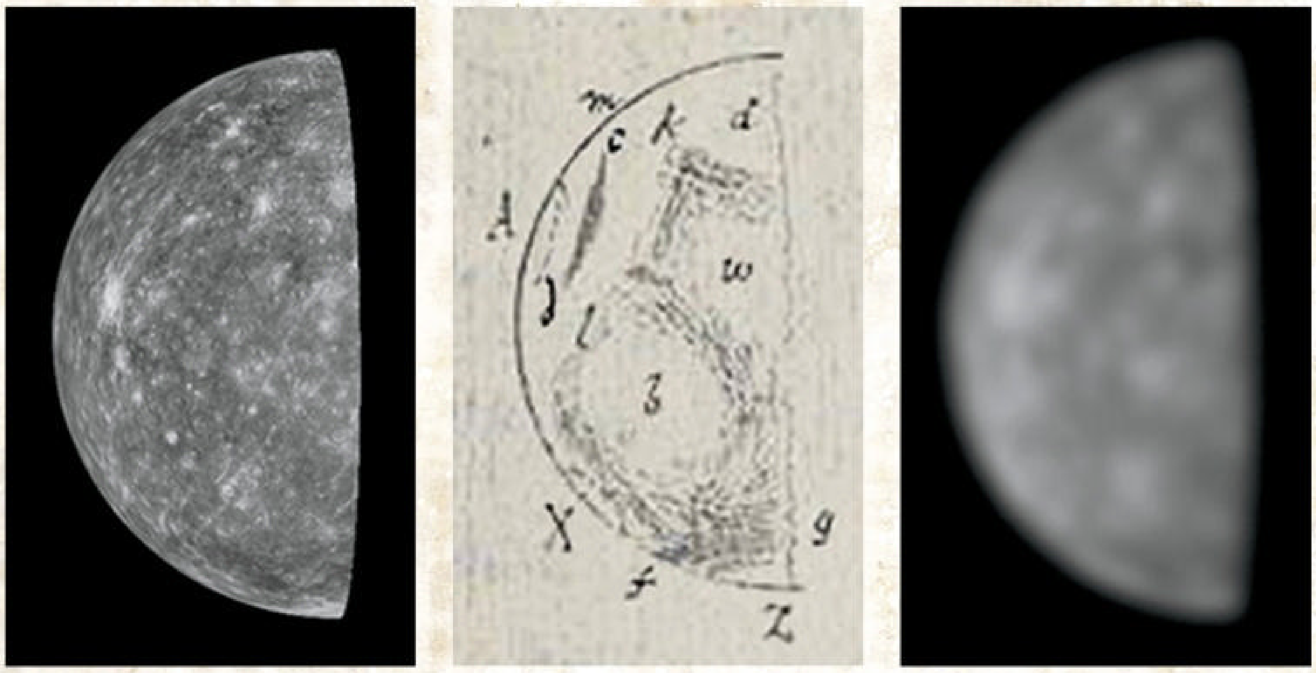
ABOVE: A 19th-century image shows Schiaparelli observing with the 49cm Merz-Repsold refractor he used in the later stages of his Mercury studies. ACHILLE BELTRAME/ LA DOMENICA DEL CORRIER (OCT. 1900)

RIGHT: A composite of images taken by the MESSENGER spacecraft's narrow- and wide-angle cameras shows an orthographic projection of this global mosaic centered at 0°N, 90°E. The peak-ring basin Rachmaninoff can be seen in the northwest portion of the globe, Rembrandt basin appears toward the south, and the edge of the Caloris basin is just visible along the eastern edge of this globe. NASA/JHUAPL/CARNEGIE INSTITUTION OF WASHINGTON

The strange history of Mercury's spots

WHAT SCHIAPARELLI SAW

Throughout this piece, we have revisited Schiaparelli's historical observations of Mercury by comparing his series of drawings with CCD images and WinJUPOS simulations. As might be expected, there are a lot of figure 5s. Some of Schiaparelli's drawings are quite accurate. But in other cases, there is so little resemblance between modern images and what he described that one has to wonder just what he thought he was seeing. — *W.S.*

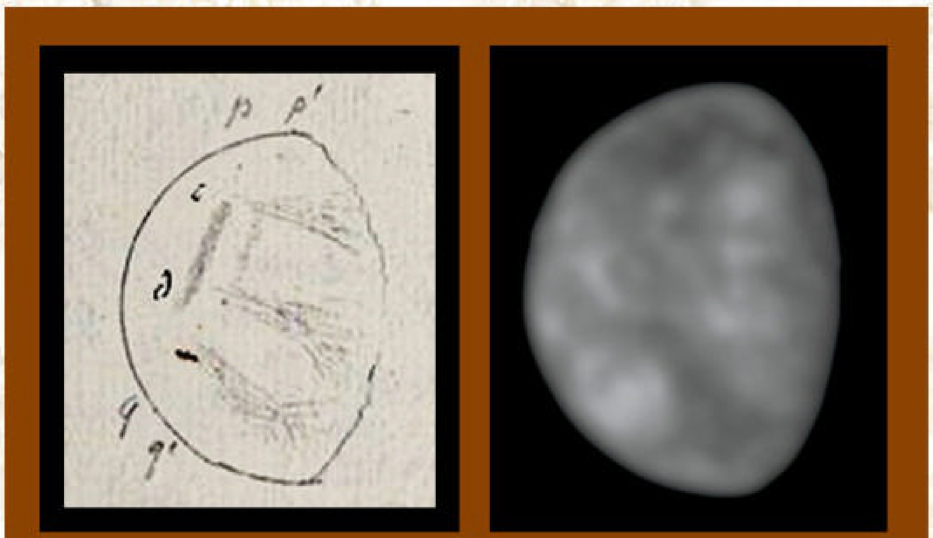


Schiaparelli's view (center) of Mercury on Feb. 6, 1882, with the central meridian (CM) at 85.6°, compared to a WinJUPOS simulation for the same date and CM (left), and a blurred version (right) that better simulates the telescopic view. The figure of 5, which made such an impression on the great Italian astronomer, is clearly evident in the simulation. MIDDLE: BRERA OBSERVATORY, MILAN. LEFT AND RIGHT: JOHN BOUDREAU

Schiaparelli targets Mercury

In the early 1880s, when Schiaparelli began his study of Mercury, he was already famous for his work mapping Mars. So, using the 9-inch Merz refractor at Brera Astronomical Observatory in Milan, he decided to extend his survey of the planets inward. Venus, as usual, offered little more than a nearly featureless disk. But Mercury seemed promising.

At the time, the early results of 19th-century German astronomer J.H. Schröter, who utilized a large reflector, still reigned. Noticing a blunting of the southern cusp of Mercury on several nights, Schröter deduced a satisfyingly Earth-like rotation period of about 24 hours. But his observations had been made during the short twilight periods, when he was forced to view the planet through the densest layers of Earth's atmosphere. Schiaparelli's telescope, meanwhile, was equipped with setting circles (by which he could pinpoint objects using their right ascensions and declinations) and a clock drive, allowing him to follow Mercury for hours. He decided to try observing the planet in broad daylight. Because Mercury was higher in the sky then, it would reward sustained inspection.



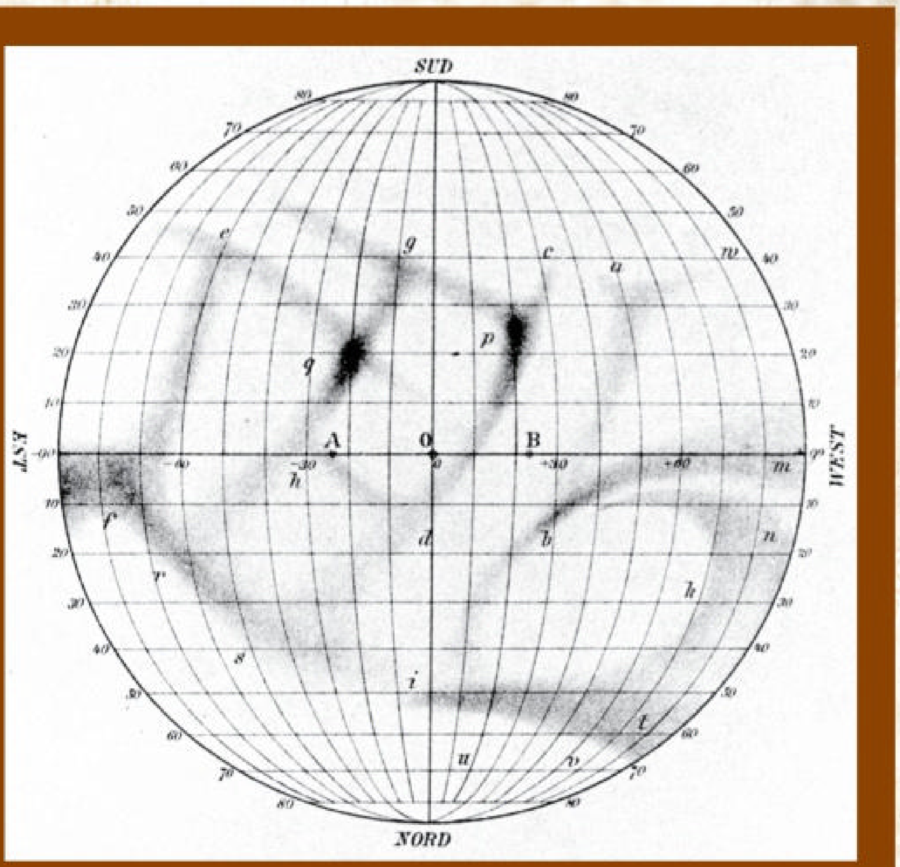
The mesmerizing figure 5 returns — or does it? Compare Schiaparelli's drawing (left) with a blurred WinJUPOS image showing the planet at the same time (May 22, 1882), with the CM at 264.8°. One really has to stare at this to make out anything resembling a 5 — and no wonder! Schiaparelli was actually looking at areas of the planet 170° in longitude apart. LEFT: BRERA OBSERVATORY, MILAN. RIGHT: JOHN BOUDREAU

Schiaparelli's initial tests of his technique in June 1881 were promising. That led to a sustained effort that began at the end of January 1882. Over the course of seven years, Schiaparelli made hundreds of observations of Mercury, as well as 150 drawings, which are preserved in the archives of Brera Observatory.

The air over Milan was turbulent during the summer, but in winter, it was often "pure and calm." That meant observations at any time of day were feasible. With his usual magnification of 200x, Schiaparelli scrutinized the tantalizing pale rose orb, which appeared through his telescope a little smaller than the Moon does with the naked eye. Markings on Mercury were almost always present, in the form of "extremely delicate streaks." But they were of such low contrast that they disappeared whenever haze or a layer of cirrus clouds intervened.

Go figure

Schiaparelli began to observe Mercury around the time of its greatest elongation east of the Sun on Feb. 6, 1882, corresponding to the planet's appearance as an evening star. On that date, he succeeded in making out a "large system of spots" on the nearly dichotomized disk. These spots, he noted, oddly combined to form the shape of the numeral 5. He denoted each part of the number with the letters *w*, *a*, *b*, *k*, and *i*. That figure 5 made a profound impression on Schiaparelli, and it was to haunt him whenever Mercury ran east of the Sun (as it did that May, when he again made out the 5). On the other hand, whenever the planet ran west of the Sun — becoming a morning star — Schiaparelli seemed to see the



Schiaparelli's famous planisphere, based on his belief that Mercury's day was the same as the planet's year, 88 days, was published in 1889.
GIOVANNI SCHIAPARELLI

same prominent dark patch, which he labeled *q*.

He made his bravest series of observations that August, when he followed the planet's tiny gibbous disk to within only 3.5° west of the Sun. This feat of observational daring, he later admitted, proved extremely damaging to his retinas. He found "the planet appears almost perfectly round, with the light only a little less than uniform; but despite the fact that the apparent diameter was reduced to 4" or 5" across, the positions of the observable markings could be judged with greater certainty than at other times." This time, he seemed to recover the dark patch *q*. In September, the next time Mercury ran east of the Sun, he once more discovered the 5. Schiaparelli's ideas were now starting to gel, and he ultimately believed the timely appearances of the observed markings confirmed Mercury's orbital period and rotational period were the same: 88 Earth days.

On Oct. 20, 1882, he wrote to his close friend and confidant François Terby, an amateur astronomer in Louvain, Belgium. Schiaparelli requested that, if he should die before he could publish, Terby should make Schiaparelli's work known "so that this beautiful result will not be lost to science." An avid classicist, Schiaparelli communicated his result to Terby in Latin verses, which read (translated):

> *Cyllenius [Mercury],*
> *turning on its axis*
> *after the manner of*
> *Cynthia [the Moon],*
> *Eternal night sustains,*
> *and also day:*
> *The one face is burned*
> *by perpetual heat,*
> *The other part, hidden,*
> *is deprived of the sun….*

More prosaically stated, one hemisphere of Mercury always faces the Sun, while the other always faces away — just like the Moon with respect to Earth. However, as in the case of the Moon, Mercury would appear to wobble (or librate) around the fixed line between it and the

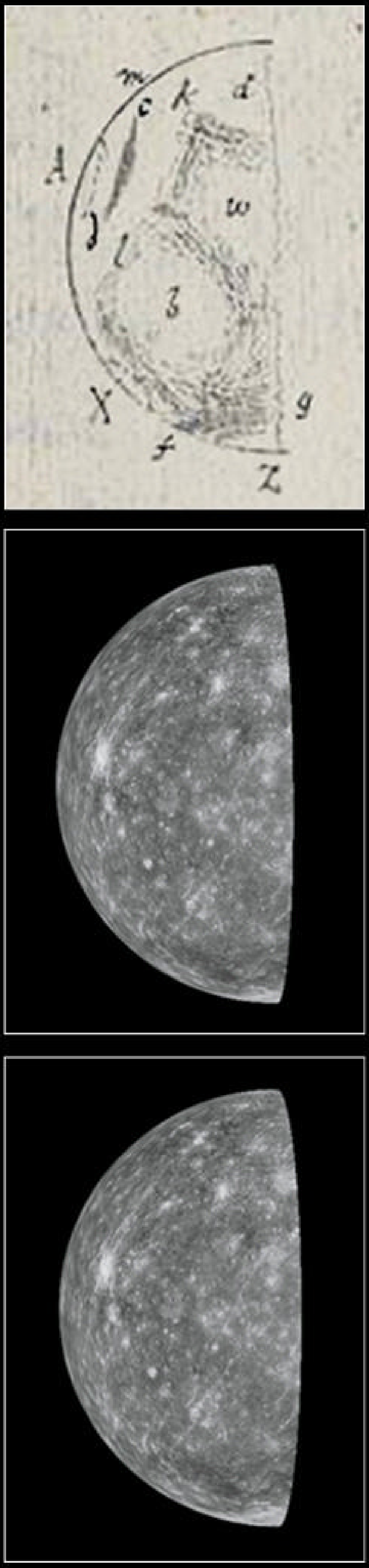
A SCHIAPARELLI CHALLENGE

In April 2022, Mercury comes to its most favorable evening apparition of the year (for Northern Hemisphere observers), advantageously placed for naked-eye and telescopic observers alike. After superior conjunction on April 2, Mercury increases its separation from the Sun, and by mid-April, it is easily visible to the naked eye. The world reaches its greatest elongation east of the Sun on April 29, when it passes only 1.5° south of the Pleiades (M45). On May 2, a thin crescent Moon joins the group. Thereafter, Mercury rapidly drops toward the Sun as it heads toward inferior conjunction on May 21.

About a week before it reaches greatest elongation, Mercury will present to telescopic observers nearly the same part of the planet that was in view when Schiaparelli began his legendary study of the world in 1882. A potentially perfect night for trying to emulate the great Italian astronomer's view is April 23. At that time, the planet's disk will be 6.8" wide, 56 percent illuminated, and the longitude of the central meridian (CM) will stand at 85° (as compared to 7.0" wide, 53 percent illuminated, and a CM at 86° on Feb. 6, 1882). Observers equipped with telescopes in the 6- to 10-inch range will want to travel back in time and take turns at the eyepiece with Schiaparelli himself in scrutinizing this once-mysterious planet.

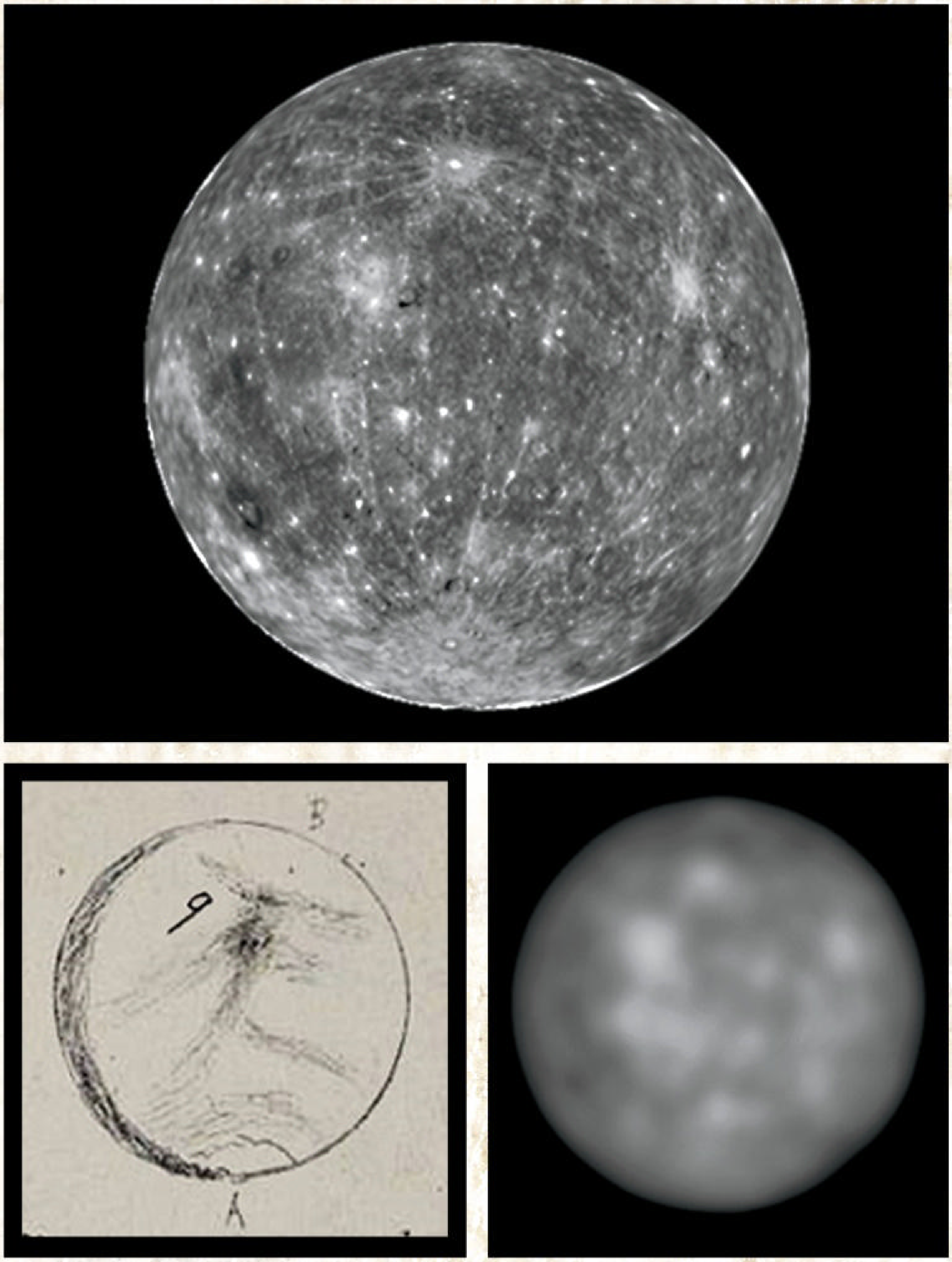
In addition to searching for the subtle figure 5, you should also look for the bright spot Kuiper, which pre-spacecraft era observers like Schiaparelli recorded as a brilliant patch and identified as a cloud. During its flyby of Mercury in March 1974, Mariner 10 discovered Kuiper is in reality a fresh, 38.5-mile-wide (62 kilometers) impact crater surrounded by a system of bright ejecta rays.

Happy sleuthing! *—Frank Melillo, W.S.*



Schiaparelli's drawing of Feb. 6, 1882 (top), compared with WinJUPOS simulations for that date (center) and April 23, 2022 (bottom). The crater Kuiper is the bright patch left of center. TOP: BRERA OBSERVATORY, MILAN. CENTER AND BOTTOM: JOHN BOUDREAU

BepiColombo took this image of Mercury during its first flyby. Over the course of its mission, the spacecraft will orbit the solar system's smallest world some 3,800 times, gathering data that will help planetary scientists unravel its history. JAXA/ESA



Schiaparelli made heroic efforts to follow Mercury to only 3½° west of the Sun, as the planet approached superior conjunction in August 1882 (an endeavor he later admitted was damaging to his eyesight). His sketch (lower left) with CM = 351.9°, was made Aug. 12, and shows a dark patch he called *q* and thought he had recorded at previous elongations west of the Sun. The blurred WinJUPOS image (bottom right) shows the same face of the planet, in which a triad of bright spots can be made out that show up more clearly in the top "Full Moon" of Mercury as the rayed craters Ellington, Debussy, and Kuiper. BOTTOM LEFT: BRERA OBSERVATORY, MILAN. TOP AND LOWER RIGHT: JOHN BOUDREAU

Sun. This effect was bound to be rather considerable, given the eccentricity of Mercury's orbit, and it provided Schiaparelli with some cover from the fact that he found the positions of his spots were quite variable over time. Yet even libration could not account for all the observed variation. In the end, Schiaparelli was forced to invoke the existence of a substantial atmosphere around the tiny planet, and even sometimes brilliant white clouds.

Despite making up his mind about Mercury's 88-day rotation and revolution period, Schiaparelli still held back from publication until he could confirm his results with a larger telescope. He eventually went on to use a 19-inch Merz-Repshold refractor, which was installed at Brera in 1886. But the observations with this larger scope did not prove decisively better than those made with the smaller Merz. At last, in late 1889, Schiaparelli put forth a memoir, in which he summarized his observations and published his famous planisphere. In December, he made a rare trip outside Milan to lecture at the Quirinal Palace in Rome to a popular audience that included the king and queen of Italy. During the lecture, Schiaparelli provocatively suggested the possibility that liquid water — and life itself — might flourish in the "twilight zone" between the perpetually sunlit and the perpetually night-shaded sides of Mercury.

Schiaparelli lived until 1910, remaining sure of his results to the end. A host of later observers lined up to confirm his results, too. Preeminent above the rest was Greek-French astronomer E.M. Antoniadi, whose long study of Mercury in the 1920s with the 33-inch refractor at Meudon Observatory near Paris seemed to definitively confirm Schiaparelli's map, his rotation period, and his clouds. Researchers came to regard Mercury's 88-day rotation period as one of the best-established facts in all of

planetary science. And yet it was all an illusion.

Dial it back

To astronomers' great surprise — and even consternation — in 1965, radio astronomers established that Mercury's rotation period was really 58.65 days, or two-thirds its orbital period. At once, it was asked how Schiaparelli and his followers could have gotten it so wrong.

One factor, identified at the time by astronomers Dale P. Cruikshank and Clark R. Chapman, involved a curious "stroboscopic effect." This is where, for several years in succession, the same side of Mercury tends to present itself during the planet's most favorable elongations (in the spring for evening observations and in the autumn for morning observations). This effect causes Mercury's surface features to appear rather static, making it difficult for observers to recognize how the markings change due to rotation. However, because Schiaparelli observed during periods other than spring and autumn, this explanation doesn't completely suffice.

Instead, it seems that because Mercury's markings are so delicate and vague in outline, subjective — that is, perception-based — factors came into play. Once an observer establishes a definite expectation, they become predisposed to seeing the expected result.

This reinforces and refines their expectations until, finally, they see an exact and detailed — but ultimately fictitious — picture. It seems Schiaparelli succumbed to such autosuggestion, falling under the spell of his own preconceptions and unable to help but fixate on Mercury's supposed number 5.

The mental trap that snared Schiaparelli was set with his first drawing of the numeral 5 on Feb. 6, 1882. And here's the pleasant surprise mentioned at the beginning of the article: During this April's favorable evening apparition on the 23rd, Mercury will display almost exactly the same face under conditions nearly identical to those Schiaparelli experienced Feb. 6, 1882.

Be sure to take a look. What do you see?

William Sheehan *is author of Mercury (London: Reaktion Books, 2018).* **Frank Melillo** *and* **John Boudreau** *monitor Mercury for the Association of Lunar and Planetary Observers. The WinJUPOs program used to create simulated views of Mercury was written by* **Grischa Hahn**.

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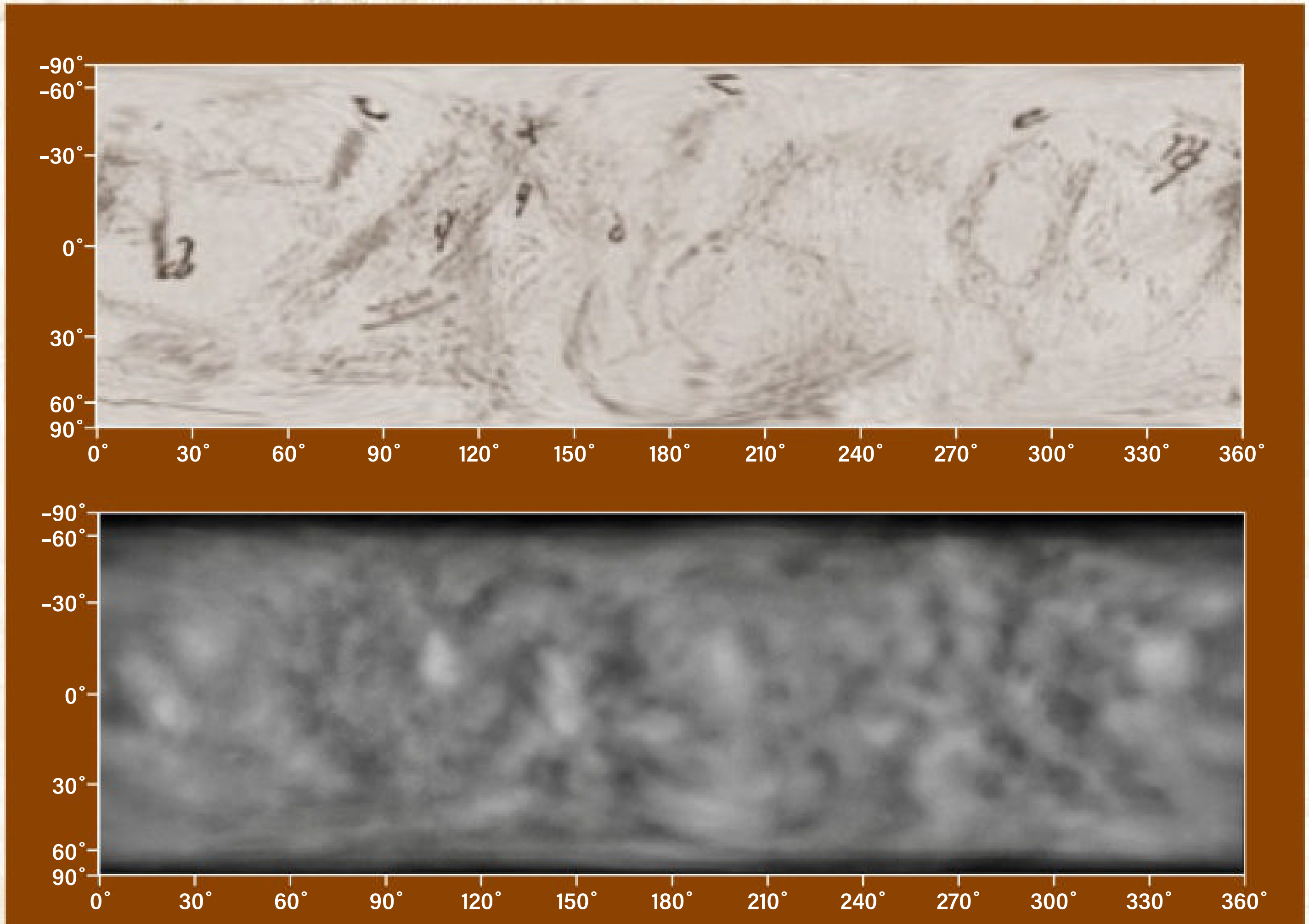


These cylindrical projections show the albedo markings of Mercury: the top based on Schiaparelli's sketches but reinterpreted using the correct rotation period of 58.65 days, and the bottom based on CCD imagery by John Boudreau using a C-11 between 2007 and 2009. JOHN BOUDREAU

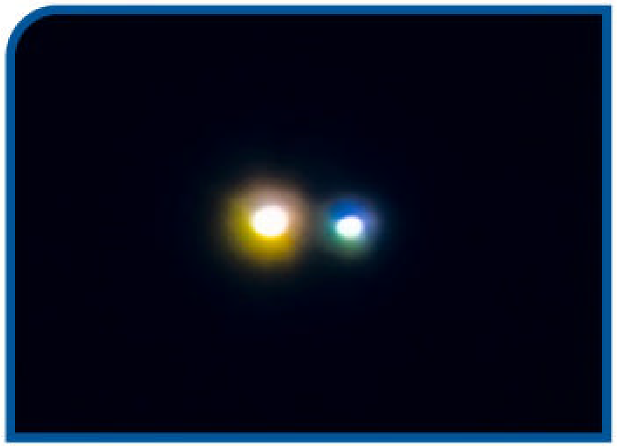
Comb through Berenice's Hair

Packed with a veritable smörgåsbord of galaxies, Coma Berenices is on full display this month.

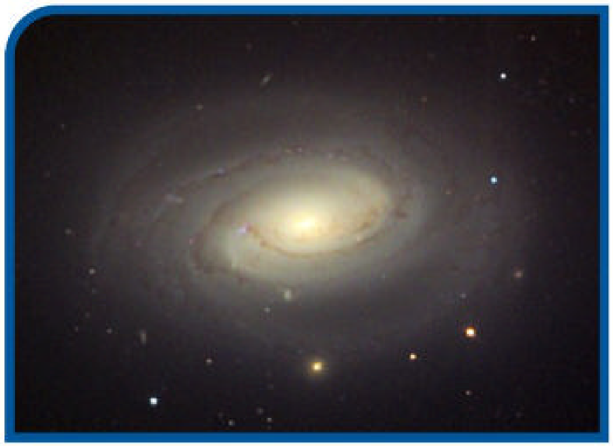
BY MICHAEL E. BAKICH

The constellation Coma Berenices (pronounced KOE-muh-bear-uh-NYE-seez), Berenice's Hair, was envisioned in its current form by Flemish cartographer Gerardus Mercator. To honor Queen Berenice II of Egypt, he placed these stellar locks on a celestial globe he designed in 1551. Unfortunately, Coma Berenices, which contains no bright stars, is not an easy star pattern to find. It's visible only from midwinter through midsummer in the Northern Hemisphere. Its center lies at right ascension 12h45m and declination 23°30'.

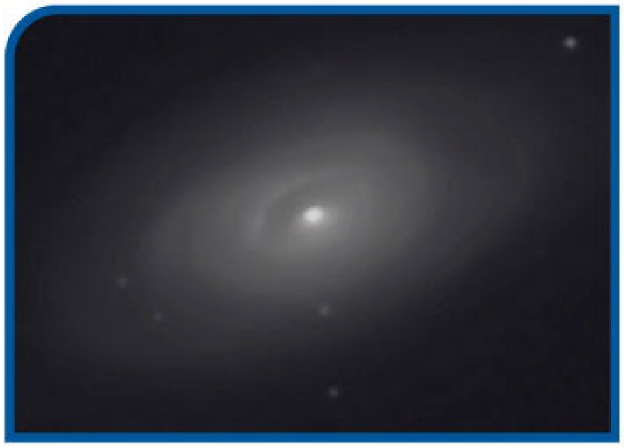
Coma Berenices ranks 42nd in size out of the 88 constellations, covering 386.47 square degrees (0.937 percent) of the sky. And while its size is middling, it fares worse (57th) in terms of overall brightness.



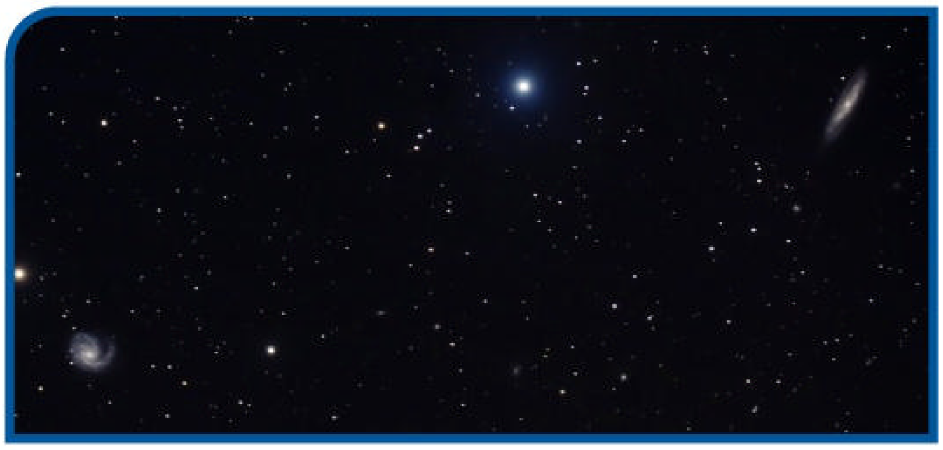
24 COMAE BERENICES For a break from galaxies, seek out the double star 24 Comae Berenices. Its components glow at magnitudes 5.2 and 6.7 and are separated by 20". Because people's eyes differ in color acuity, some observers see yellow and blue, others see both as white, and still others see the pair as orange and green. ALAN DYER



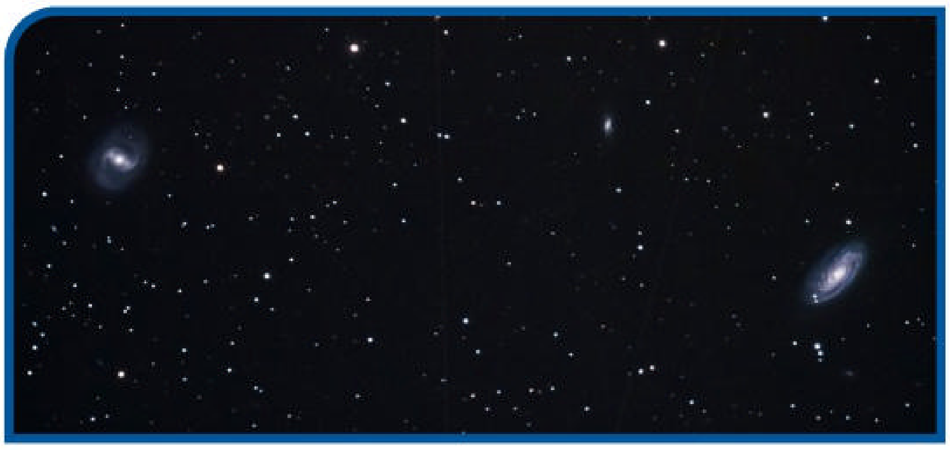
NGC 4450 To locate spiral NGC 4450, look just south of the midway point of the line that connects the stars 11 and 25 Comae Berenices. The galaxy is relatively bright (magnitude 10.1) and oval (5.0' by 3.4'). A thick halo surrounds a stretched-out core. ADAM BLOCK (NOAO/AURA/NSF)



M64 The Blackeye Galaxy (M64) got its name after William Herschel discovered its dark dust feature, which he compared to a black eye. That light-obscuring dust lane is prominent, but only when viewed through a 10-inch scope. M64 glows at magnitude 8.5 and measures 9.2' by 4.6'. ALAN DYER



M98 & M99 The magnitude 10.1 spiral galaxy M98 (upper right) measures 9.1' by 2.1'. It lies 7.2° east of Denebola (Beta [β] Leonis). Through an 8-inch scope, its center looks broad and slightly brighter than its arms. And a larger telescope will reveal star-forming regions in those arms. The Pinwheel Nebula (M99) is actually a spiral galaxy sometimes called St. Catherine's Wheel, a rather gruesome comparison considering the purpose of its namesake device. It glows at magnitude 9.9 and spans 5' by 4.6'. Through a 10-inch scope, M99 appears to have only one arm. Go bigger to see the other two. ALAN DYER

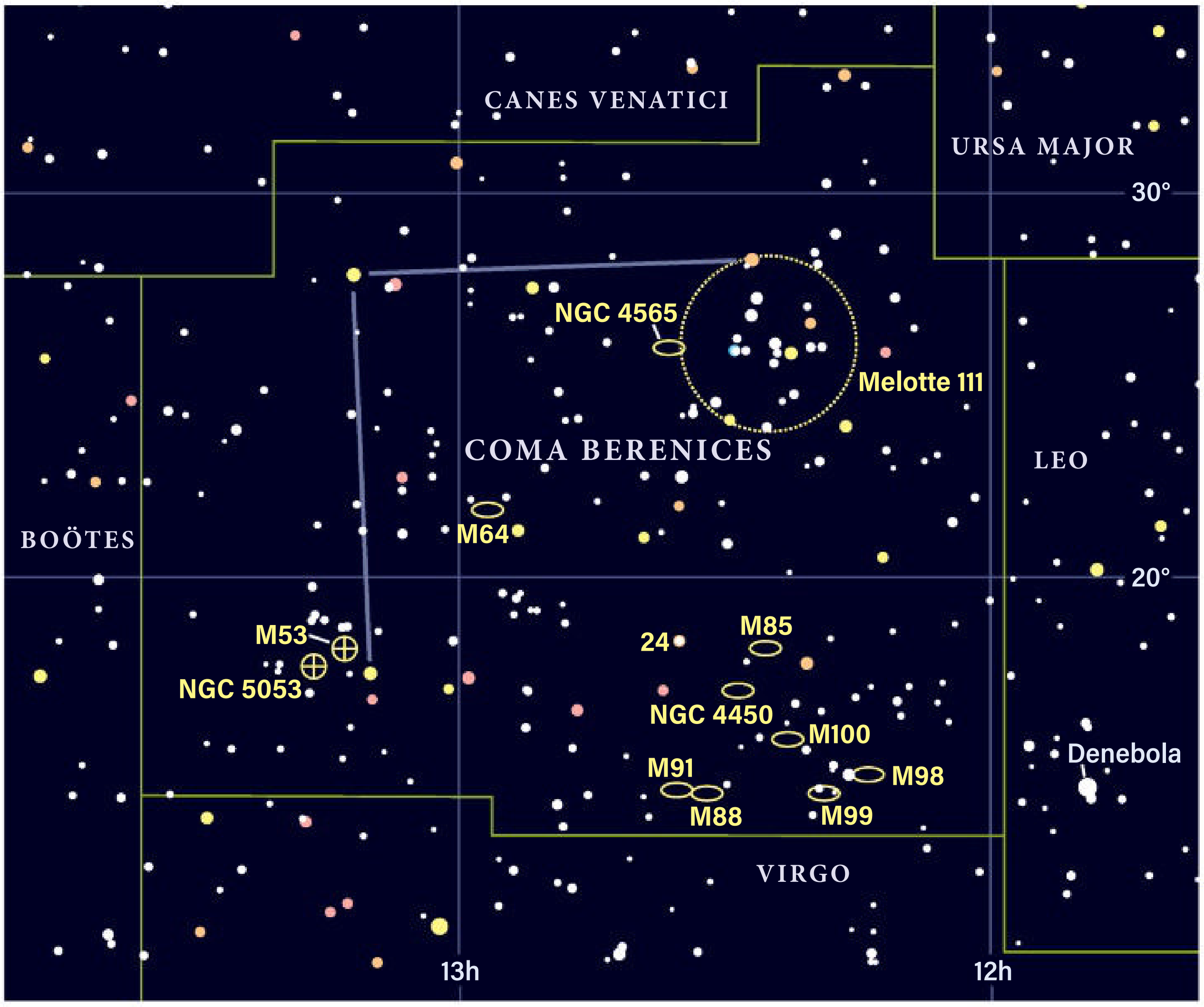


M88 & M91 Spiral galaxy M88 (right) resides in a region housing hundreds of other galactic tenants. Fortunately, at magnitude 9.6, it outshines them all. Through a 6-inch telescope, M88 is an oval haze more than twice as long as it is wide (6.1' by 2.8'). A 12-inch scope at 300x will reveal some of the spiral's structure. The easiest way to find the magnitude 10.2 barred spiral M91 (left) is to start at M88 and move 0.8° east. A 6-inch telescope shows a rectangular-shaped object a bit longer than it is wide (5.0' by 4.1'). With a high-power eyepiece in a 12-inch scope, you'll easily see its central bar. ALAN DYER

The best date to see Coma Berenices is April 2, when it stands opposite the Sun in the sky and reaches its highest point at local midnight. The constellation is completely visible from latitudes north of 56° south, and it remains entirely invisible only between latitude 77° south and the South Celestial Pole.

Although this star pattern isn't particularly expansive or bright, it contains no less than eight Messier objects, the third most of any constellation. You'll also find lots of other worthy targets tangled up in Berenice's Hair. Let your telescope adjust to the outside temperature, get comfortable, and spend an enjoyable night combing through the great deep-sky objects in Coma Berenices. Good luck!

Michael E. Bakich *is a contributing editor of* Astronomy *who enjoys slowly moving his telescope through a single constellation.*



ASTRONOMY: RICHARD TALCOTT AND ROEN KELLY

M100 Spiral galaxy M100 ranks as one of the brightest galaxies (magnitude 9.4) in the Coma-Virgo cluster, so it's a great target for amateur scopes. It lies not quite 2° northeast of the star 6 Comae Berenices. Through an 8-inch scope, the arms appear as bright regions to the east and west of the nucleus. BILL SNYDER

NGC 4565 No. 1 on any list of edge-on spirals is the Needle Galaxy (NGC 4565). It glows at magnitude 9.6 and measures 14.0' by 1.8'. An 8-inch telescope reveals a streak roughly 10' long that's oriented northwest to southeast. To see NGC 4565's full extent, move up to a 16-inch scope. ALAN DYER

M85 At magnitude 9.1, lenticular galaxy M85 is one of the sky's brightest galaxies. It lies 1.2° east-northeast of 11 Com. A 12-inch scope will reveal the brightness difference as you move out from the core, as well as the galaxy's overall subtle yellow color. The smaller barred spiral galaxy to its left is NGC 4394. LEE BUCK

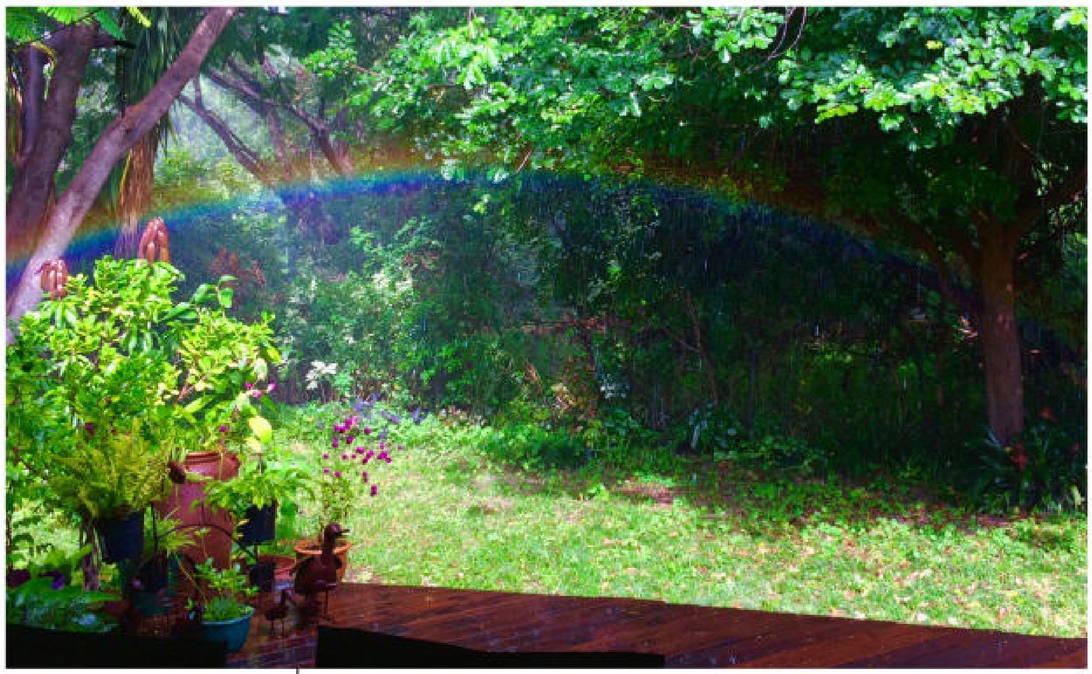
M53 & NGC 5053 Globular cluster M53 (upper right) lies not quite 1° northeast of Diadem (Alpha [α] Com). It glows at magnitude 7.7, so a 4-inch scope will reveal several dozen of its stars. M53 has a diameter of 12.6'. And because few stars are near the cluster, you'll have no trouble defining its edge. Globular cluster NGC 5053, which looks like an open cluster, lies in the same field as M53. It's a bit smaller (10.5') and, at magnitude 9.9, more than two magnitudes fainter. You'll need an 8-inch telescope to resolve its stars, which form a rough triangle. ALAN DYER

MELOTTE 111 The Coma Berenices star cluster (Melotte 111) contains some 40 stars between magnitudes 5 and 10. Their light combines for a total magnitude of 1.8. Because this object spans more than 4°, start with 50mm or larger binoculars. After that, move to your telescope and select your lowest-power eyepiece. ALAN DYER

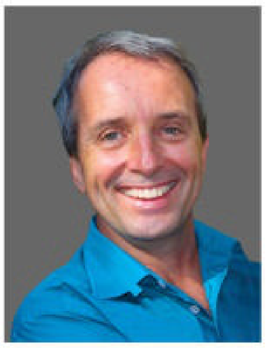
SECRET SKY

The impropriety of rainbows

Rainbows exist at an uneasy nexus of light, shadow, and water.



An “improper” rainbow appeared in the author’s garden in Maun, Botswana, during a “monkey’s wedding” in March 2021. STEPHEN JAMES O’MEARA



BY STEPHEN JAMES O’MEARA

Stephen is a globe-trotting observer who is always looking for the next great celestial event.

I never thought the day would come when an “improper” natural phenomenon would display itself out in the open air.

I’ll explain: I’m talking about rainbows. “Improper” may seem an ill-fitting term, but rainbows have a darker side. After all, rainbows exist when rain and the Sun are juxtaposed in the sky. This makes them a rich topic, scientifically and ethnologically.

For instance, we’re used to the sight of a rainbow arc soaring above the horizon. But rainbows can be seen underneath the horizon as well, projected against the ground.

That’s because rainbows are centered on the spot in the sky directly opposite the Sun, called the antisolar point, with a radius of 42°. When the Sun is at an altitude of 42°, the tip of the rainbow’s arc just touches the horizon. When the Sun is higher, the full arc is seen against the ground.

The rainbow is a universal sign of malevolent spiritual presence.

One can usually see a rainbow underneath the horizon line whenever the Sun shines on, say, the spray of a waterfall, or from a fountain — not to mention from an ordinary garden hose. But in each of these cases, something other than rain generates the phenomenon.

On the afternoon of March 25, 2021, I witnessed for the first time a rainbow that arced below the horizon during a rain. The rainbow formed when the tail-end of a thunderstorm had passed but its strong winds lingered, which shot rain into our garden just as the Sun broke free from an obscuring cloud. The bow was only yards away, arcing beneath the trees.

At first, I thought I was being fooled, reasoning that our plot’s gardener must have left a lawn sprinkler on during the storm. But that wasn’t the case. Quickly, I realized that I was “a monkey’s uncle” — in a state of surprise and disbelief. And therein lies a story.

Umshado wezinkawu

In southern Africa, whenever it rains while the Sun is shining, people say it’s a “monkey’s wedding.” The influential Austronesian linguist Robert Blust, who died Jan. 5, said the expression almost certainly derived from the Zulu expression *umshado wezinkawu*: “a wedding for monkeys.” I appreciate the Zulu translation, as it rings familiar. For instance, in English we might say something is “for the birds,” or it “has gone to the dogs.”

Having lived in southern Africa now for several years, my take on the expression is that a sun-shower represents a union of the Sun and rain that’s best fit for monkeys — an animal known in mythology for creating chaos.

The expression fascinates because, while no one knows clearly what it means, it is used in folklore across the globe to describe a sun-shower, albeit with minor twists. For instance, in Japan, and parts of Europe and Asia, a sun-shower is known as the “fox’s wedding”; in Lebanon and Syria, it’s the “rat’s wedding”; in parts of Northern Africa, it’s the “hyena’s wedding”; and in Afrikaans, it’s the “jackal’s wedding.” One common theme is the clever nature of the selected animal.

In in a 1994 issue of *Anthropos*, Blust wrote, “The essential constellation of features [of the expression] appears to involve animal parturition or conjugal union in connection with sunshowers, or, less often, rainbows.”

And what of the rainbow? Despite scattered positive associations, such as in the Judeo-Christian tradition, in the world’s preliterate cultures, the rainbow is a universal sign of malevolent spiritual presence, said Blust.

As he explained, “[W]ithin prescientific cultures the natural causality of rainbows is completely obscure, and such a visually stunning and awe-inspiring phenomenon can only be attributed to supernatural agency.” In later work, Blust argued that rainbows inspired the varied myths of dragons around the world: In many cultures, rainbows are portrayed as possessive serpents guarding precious fresh water, drinking the rain and causing it to cease.

Some cultures emphasize other supernatural elements in describing a sun-shower: “witches weep”; “the devil fights and gets married”; “fairies comb their hair.” Whatever your preference, send your sightings of *rain*-induced earthly bows to sjomeara31@gmail.com.

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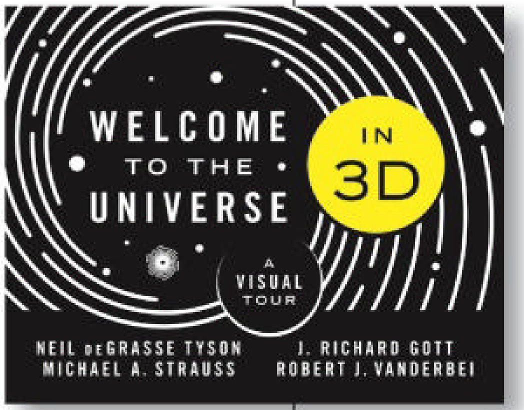
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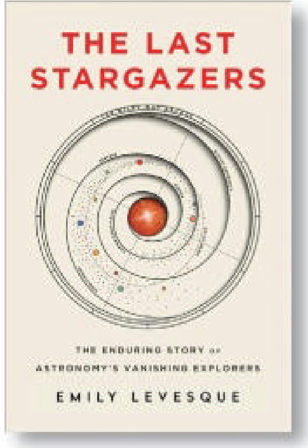
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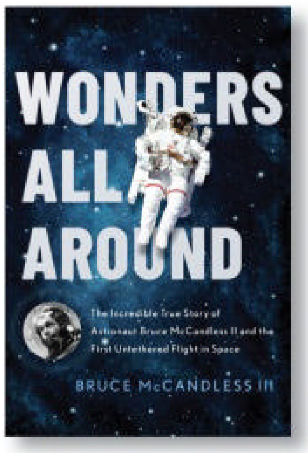
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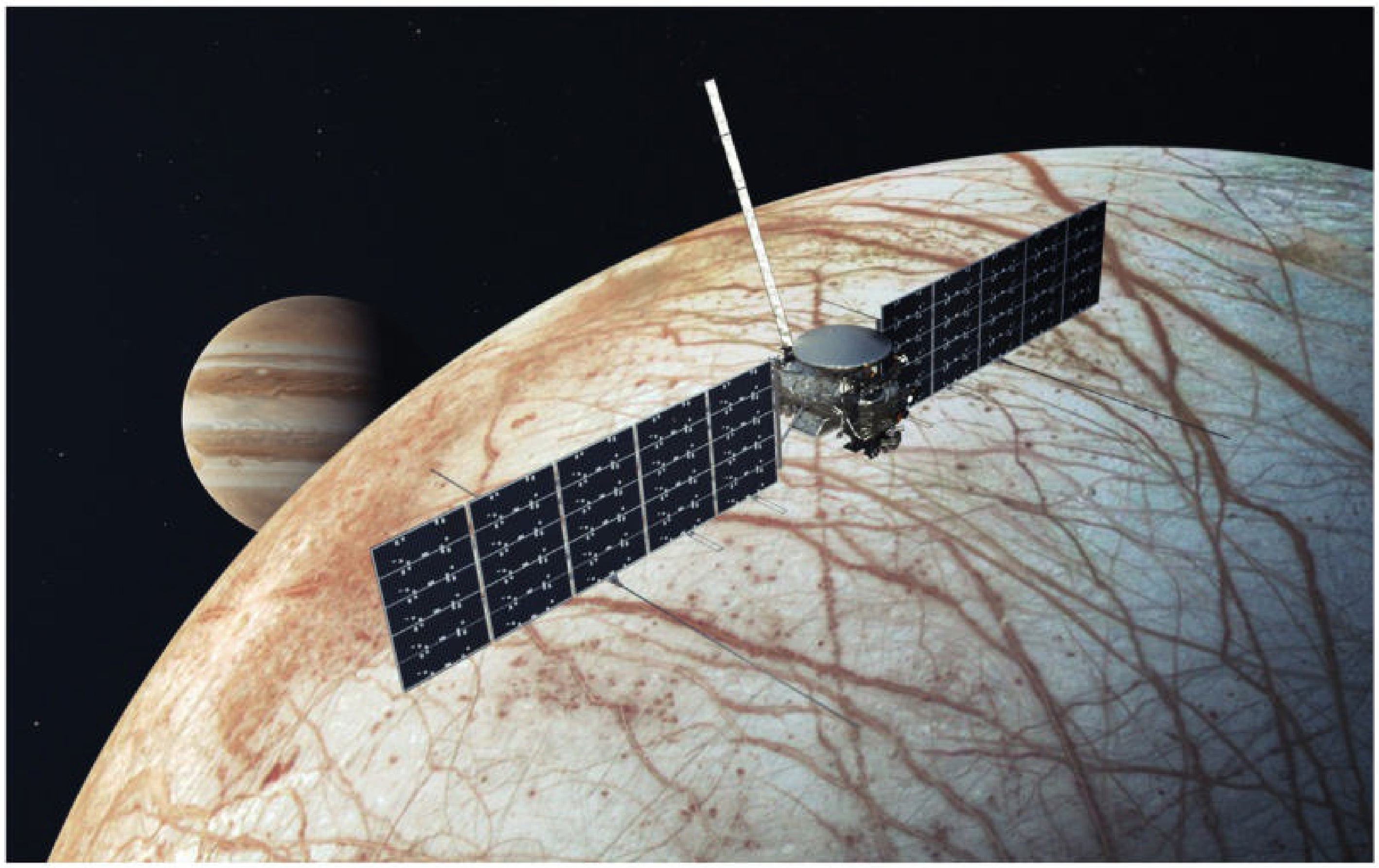


NASA's Europa Clipper performs a flyby of the jovian moon in this artist's concept. NASA/JPL-CALTECH

Safe zone

Q | WHY WILL EUROPA CLIPPER ORBIT JUPITER INSTEAD OF EUROPA?

Gary Duemling
Prescott, Arizona

A | NASA's Europa Clipper spacecraft is scheduled for launch in 2024, carrying 10 instruments that will assess the habitability of Jupiter's moon Europa. The craft will follow up on discoveries by the Galileo mission of the 1990s, which orbited Jupiter and made multiple flybys of both the planet and its major satellites. As you point out, Europa Clipper will orbit Jupiter. However, it will solely focus on Europa, performing some 50 close passes of the ocean-sporting moon during its primary mission.

So why will it orbit Jupiter and not Europa itself? One word: radiation. Jupiter's powerful magnetic field traps and accelerates charged high-energy particles, producing a doughnut-shaped radiation belt that rotates with the planet. Europa orbits Jupiter within this high-radiation zone, and so is continuously exposed to this harsh environment. The radiation belt is damaging to spacecraft and instrument electronics, leading to rapid degradation if unaccounted for.

A 2011 NASA study assessed both a Europa-orbiting spacecraft and a Jupiter-orbiting "Multiple-Flyby Mission" option. Around Europa, an orbiting spacecraft would be limited to a lifetime of a mere one month due to this continuous radiation exposure. In contrast, the highly elliptical orbit of the multiple-flyby Europa Clipper mission means it will spend most of its time outside of the high-radiation zone, only being briefly exposed to it during its quick passes by the moon. As an added bonus, its long elliptical orbit also permits the craft to transmit collected flyby data back to Earth, as well as perform additional functions between Europa encounters (typically two to three weeks apart).

Europa Clipper's multiple-flyby architecture will yield significantly more data than a Europa-orbiting mission, and cleverly designed trajectories will permit near-global high-resolution mapping. As of now, the Europa Clipper spacecraft is taking shape in "shipyard" facilities across the country and overseas. We hope you continue to follow the Europa Clipper mission as we proceed toward unprecedented science!

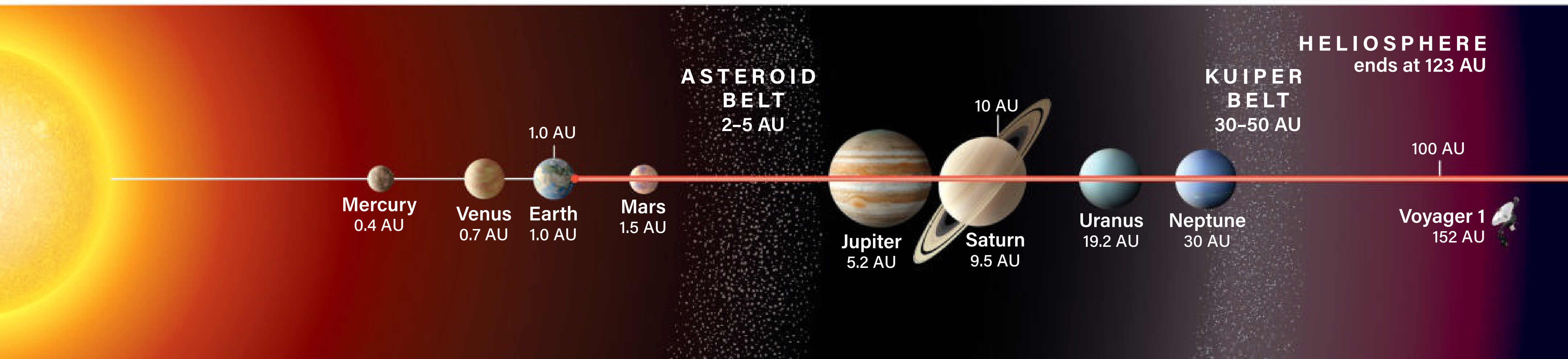
Cynthia Phillips
Project Staff Scientist, Europa Clipper Mission,
NASA Jet Propulsion Laboratory, Pasadena, California

Q | DOES OUR OORT CLOUD OVERLAP WITH ALPHA CENTAURI'S?

Carles Martinez
Barcelona, Spain

A | About 2,000 to 5,000 astronomical units (AU; where 1 AU is the average distance between Earth and the Sun) from the Sun lies the beginning of the Oort Cloud. For context, the Voyager spacecrafts

The Oort Cloud, a collection of icy bodies left over from the birth of the solar system, lies somewhere between 2,000 to 100,000 astronomical units (AU) from our star. *ASTRONOMY*: ROEN KELLY



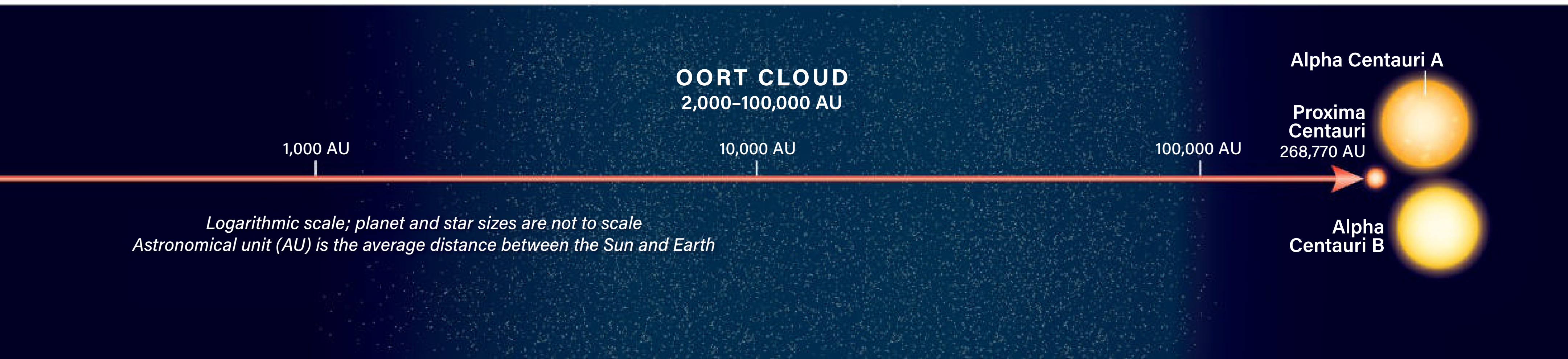
— the human-made objects that have traveled farthest from our Sun — will cross this inner edge of our solar system in about 300 years. From there, the Oort Cloud stretches to about 10,000 to 100,000 AU (0.16 to 1.6 light-years), according to NASA. But keep in mind this outer boundary is pretty nebulous, so there is no hard line where the Oort Cloud ends.

All this is to say that it isn't clear how close the Oort Cloud actually gets to the Alpha Centauri system, which is about 4.3 light-years away. Even if the Oort Cloud does stretch halfway to the other system, scientists aren't sure whether it has its own Oort Cloud.

Despite searching, astronomers have seen no direct evidence of extrasolar Oort Clouds (and they've been looking since 1991). Because these clouds would be so far from their stars and aren't very dense, spotting them would be exceedingly difficult.

Our Oort Cloud *is* influenced by other systems. The Oort Cloud is outside of the Sun's heliosphere — the protective magnetic bubble that separates our solar system from interstellar space. The solar system also sits closer to the edge of the Milky Way than the center. This means that one side of the solar system feels a stronger gravitational pull than the other. This gradually jostles the Oort Cloud, sometimes sending long-period comets into the inner solar system. Passing stars and molecular clouds can have similar effects. Likewise, as our nearest celestial neighbor, the Alpha Centauri system likely has some effect, albeit a small one, even at its distance. But Alpha Centauri is actually approaching the Sun. In about 30,000 years, the trio of stars will come within about 2.9 light-years of our star, at which point its influence will be much stronger.

Caitlyn Buongiorno
Associate Editor



Logarithmic scale; planet and star sizes are not to scale
Astronomical unit (AU) is the average distance between the Sun and Earth

Q | HOW FAR AWAY IS THE COSMIC MICROWAVE BACKGROUND?

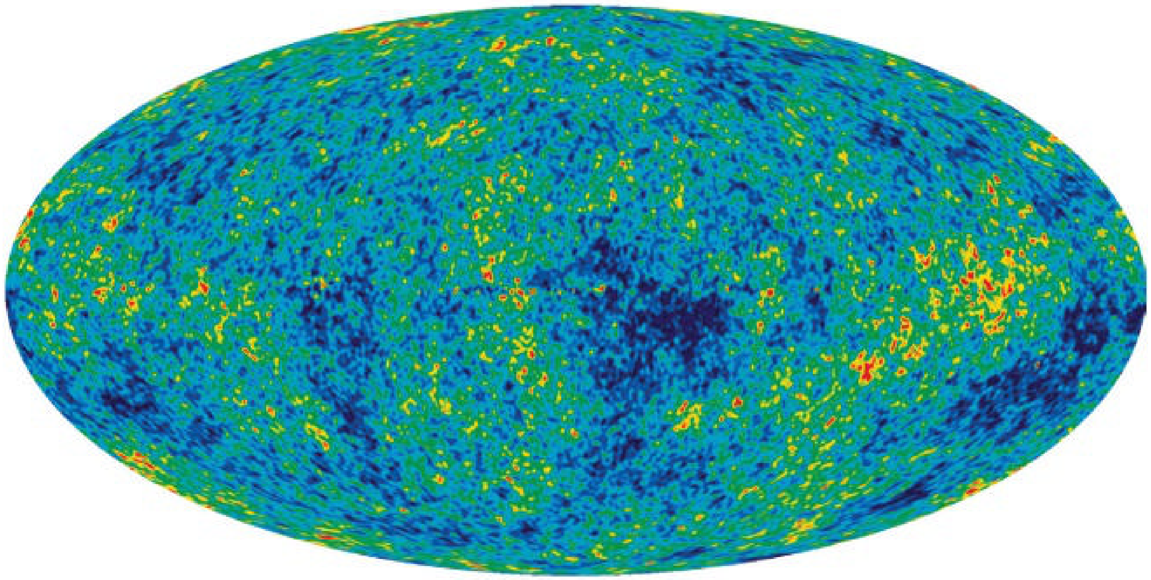
Nick Smith
New Port Richey, Florida

A | The cosmic microwave background (CMB) is the radiation allowed to freely propagate after the universe cooled enough for electrons to combine with atomic nuclei to form neutral atoms some 300,000 years after the Big Bang, or roughly 14 billion years ago. This CMB radiation was mostly in the form of near-infrared light, but the wavelength of the CMB light has been stretched by the expansion of space so much it now falls in the microwave range we see today. This expansion of the universe describes the phenomenon whereby the distance between any two points in space gradually increases over cosmic time. So, the CMB source is 40 billion light-years away and not 14 billion light-years away, as one might expect.

Observations of the CMB convert the light signal into a map of the relative temperature of the radiation. From Earth, we observe slightly hotter and colder spots in the CMB across the sky. We relate these to small (a few parts in a million) differences in the density of matter at that location at the time the CMB formed. Although higher density regions are considered the seeds for large-scale structures like galaxy clusters, individual locations of hot/cold spots in the observed CMB do not tell us anything particularly insightful. Everything we can learn about the CMB is encoded in the distribution of the numbers and sizes of these hot/cold spots.

The cosmological principle postulates that the universe, as a whole, is isotropic and homogeneous. Isotropy means that the universe appears statistically identical in every direction. While the CMB appears different at varying sightlines, the universe evolves in a uniform manner such that the CMB is the same distance in all directions. Homogeneity means that the universe appears statistically identical no matter where you are. The CMB will certainly appear slightly different from any distant galaxy, but the statistical distribution of hot/cold spots (and the cosmological information contained within) should be exactly the same.

Victor Chan
David A. Dunlap Department of Astronomy & Astrophysics,
University of Toronto, Toronto, Canada



Differences in the density of the early universe can be seen in the variations within the cosmic microwave background. These differences are the seeds that eventually grew into clusters of galaxies. NASA/WMAP SCIENCE TEAM

SEND US YOUR QUESTIONS

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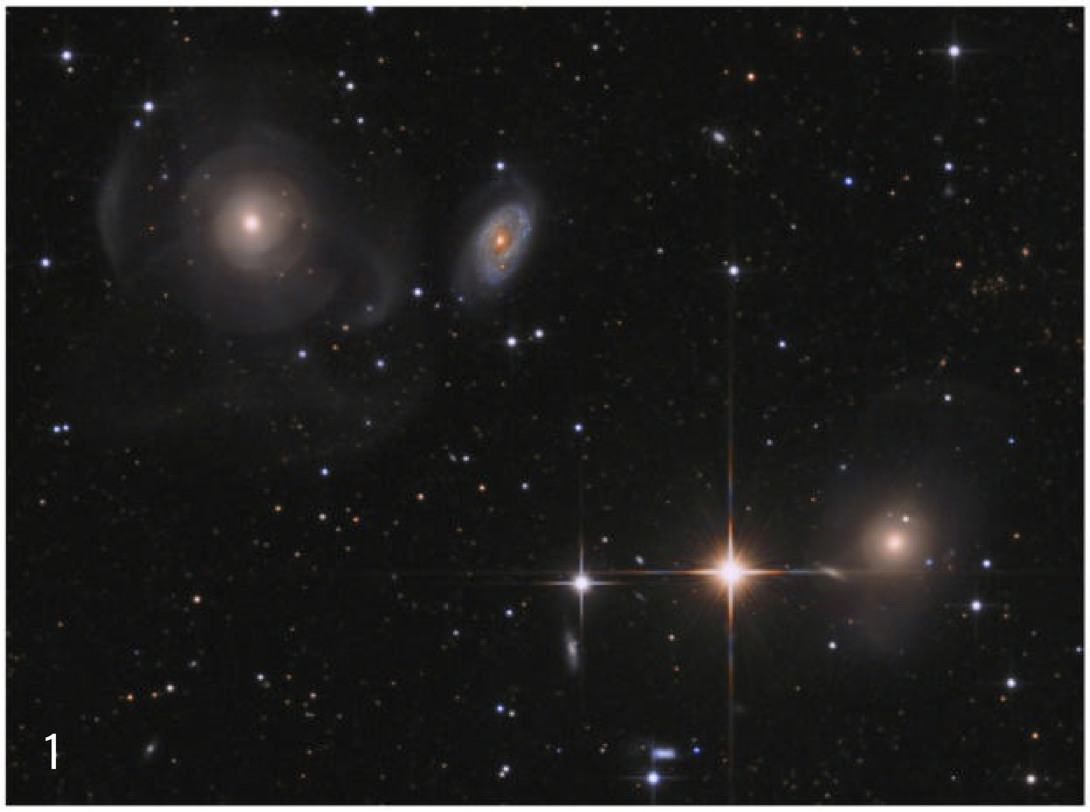
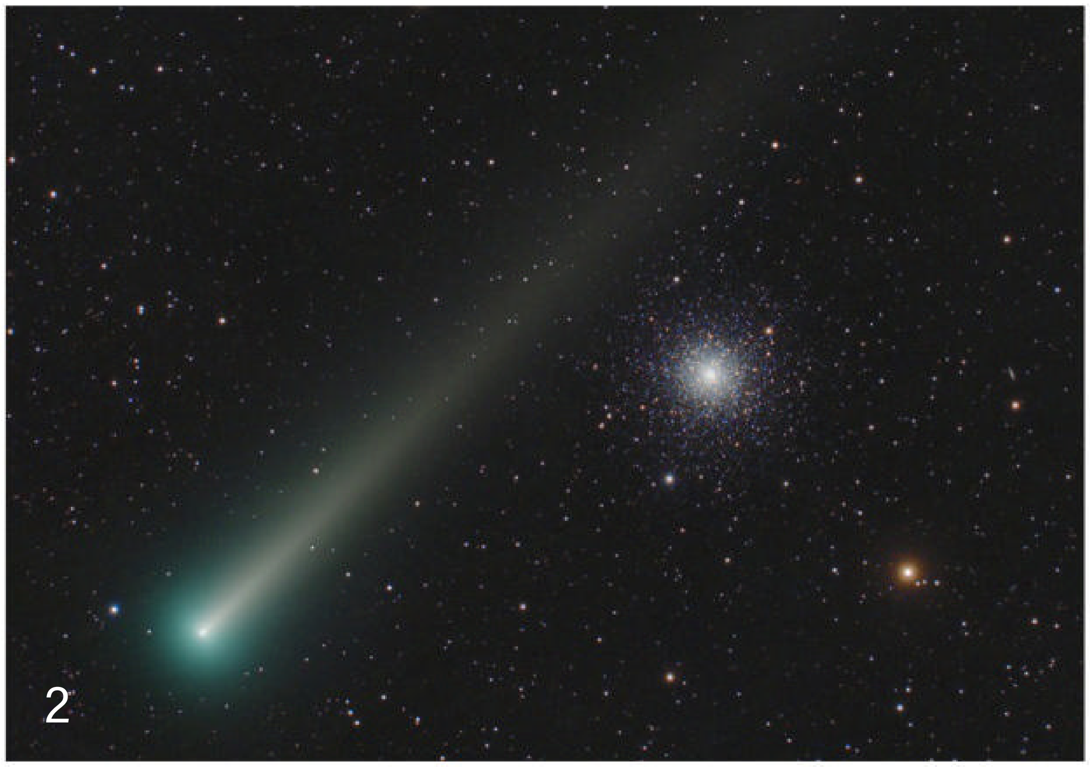
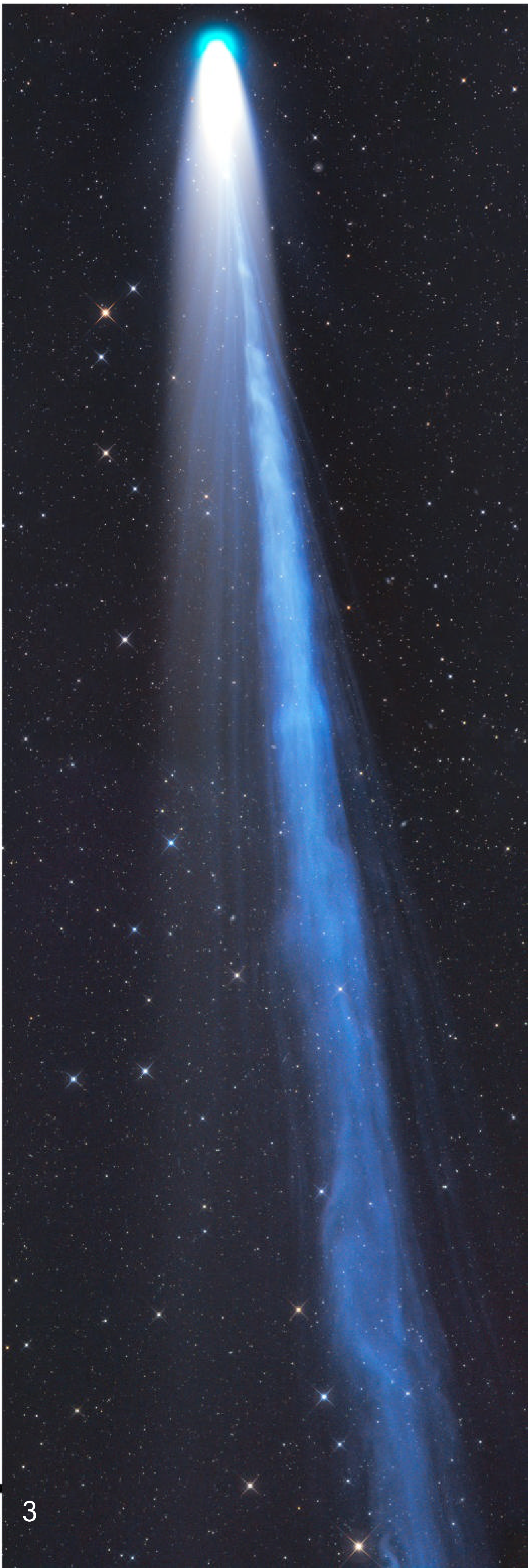
Cosmic portraits



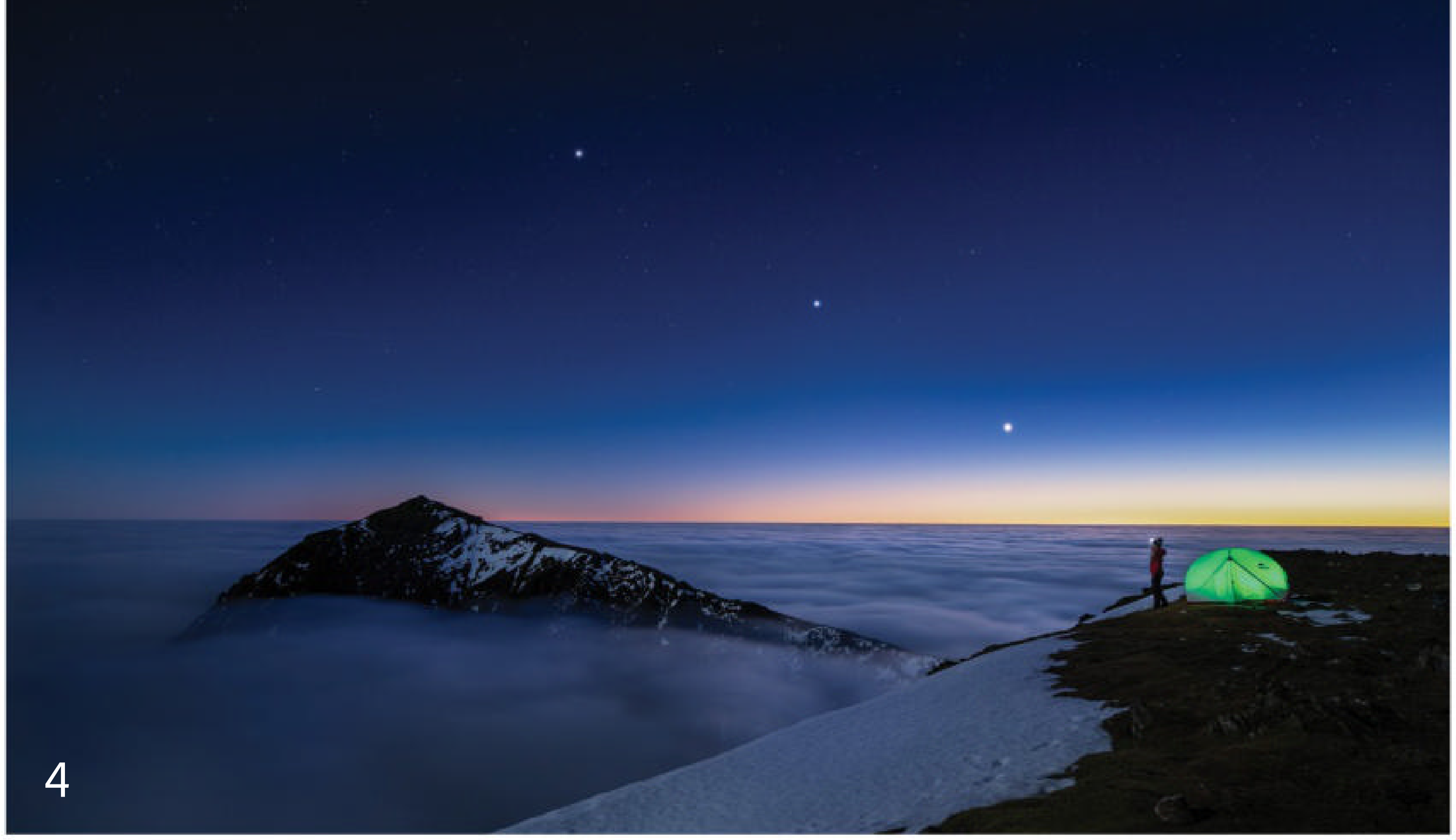




1. SHELL OF A GALAXY
Arp 227 (upper left) is an interacting pair of galaxies in Pisces roughly 100 million light-years distant. The larger of the two, NGC 474, is an elliptical with multiple shells and tidal tails formed by the influence of neighboring NGC 470. At lower right is elliptical NGC 467, which also shows evidence of interaction. This image was taken with a 4.3-inch scope and 15.3 hours of exposure in LRGB. **▪ *Sergey Trudolyubov***

2. LEONARD ARRIVES
Comet C/2021 A1 (Leonard) closed out 2021 with a spectacular display, brightening into the best comet of the year. On Dec. 3, it passed the 6th-magnitude globular cluster M3 in Canes Venatici. This shot was taken with a 3.2-inch refractor and 81 minutes of exposure. **▪ *Chris Schur***

3. AS CLOSE AS IT GETS
Comet Leonard reached perihelion — its closest approach to the Sun — Jan. 3. This image is a mosaic of two LRGB panels taken that evening with an 8-inch scope and 4.5 minutes of exposure with each filter. **▪ *Gerald Rhemann***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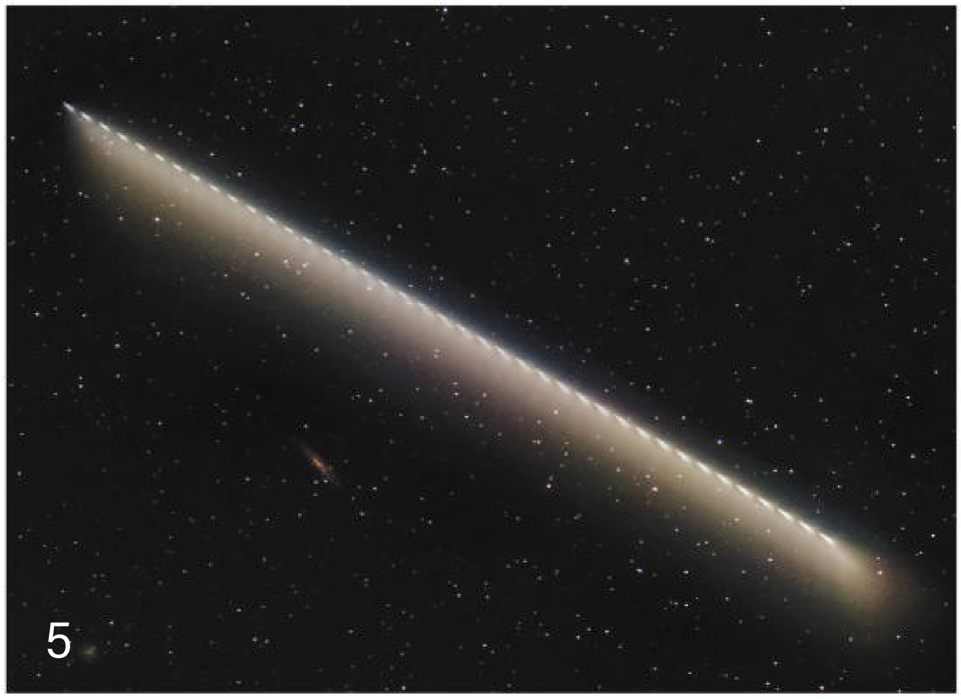
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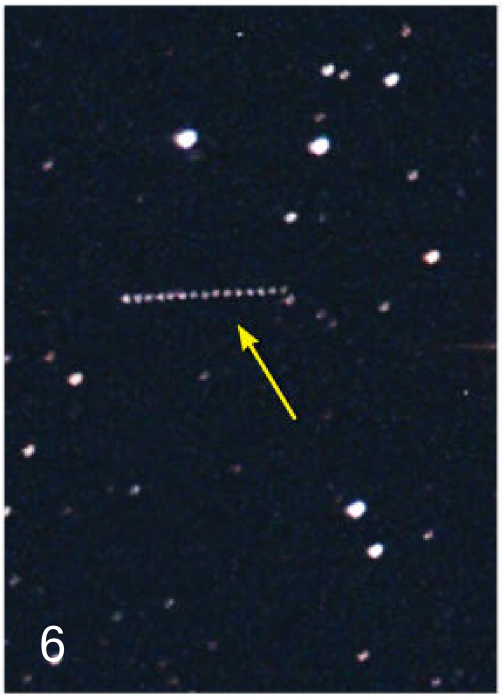
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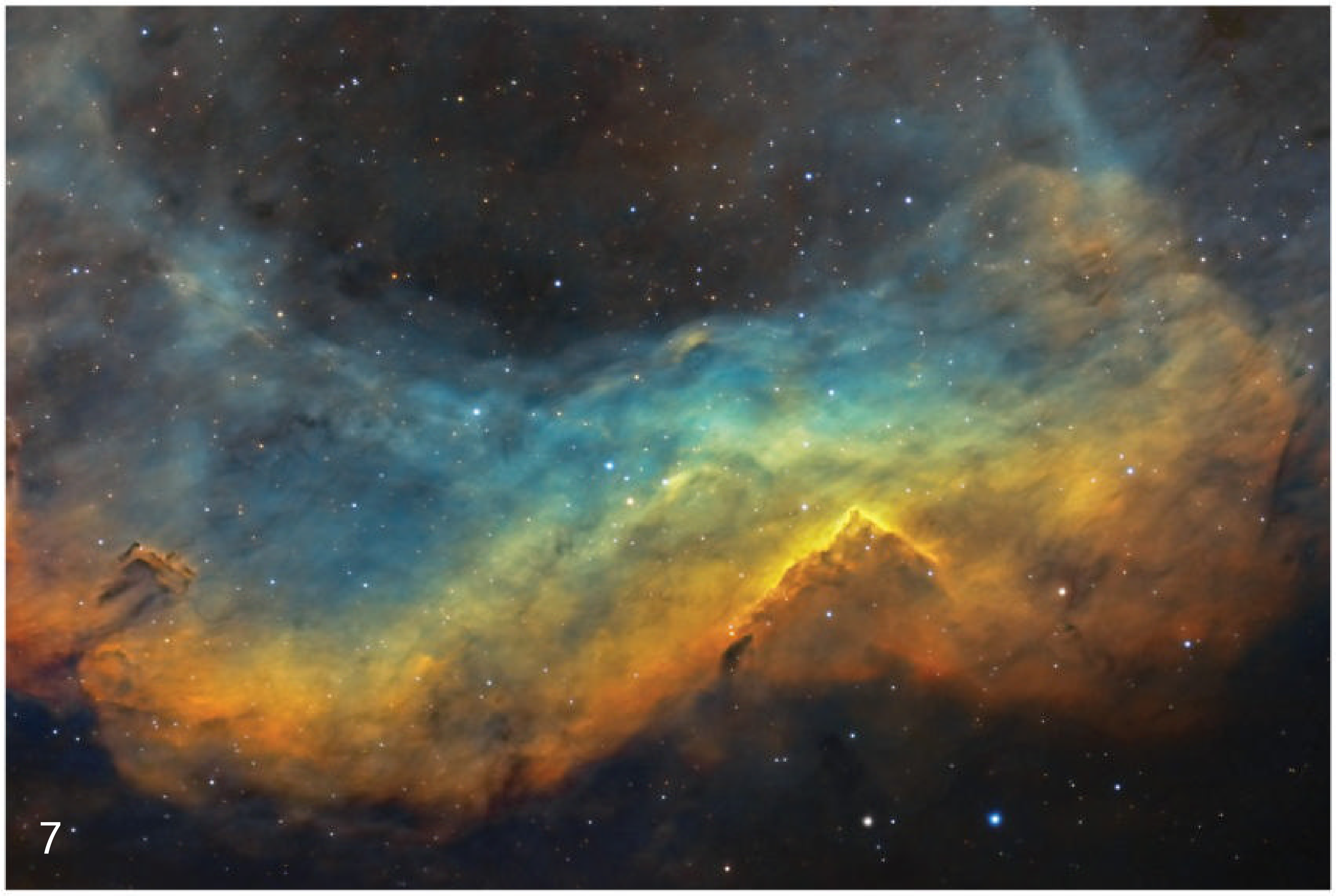
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4. ABOVE THE SNOW LINE

The planetary trio of Jupiter, Saturn, and Venus (left to right) shines above Snowdon, the highest mountain in Wales at 3,560 feet (1,087 meters). This shot was taken Dec. 16 from neighboring peak Garnedd Ugain. **• *Kat Lawman***

5. JWST'S JOURNEY

NASA's James Webb Space Telescope rocketed to space Dec. 25 aboard an Ariane 5 launcher. This imager captured the second stage passing the Sculptor Galaxy (NGC 253) from Sukna in West Bengal, India. The image is a series of 40 two-second exposures with a Nikon D5600 and a 135mm f/2 prime lens at ISO 500. **• *Samit Saha/Soumyadeep Mukherjee***

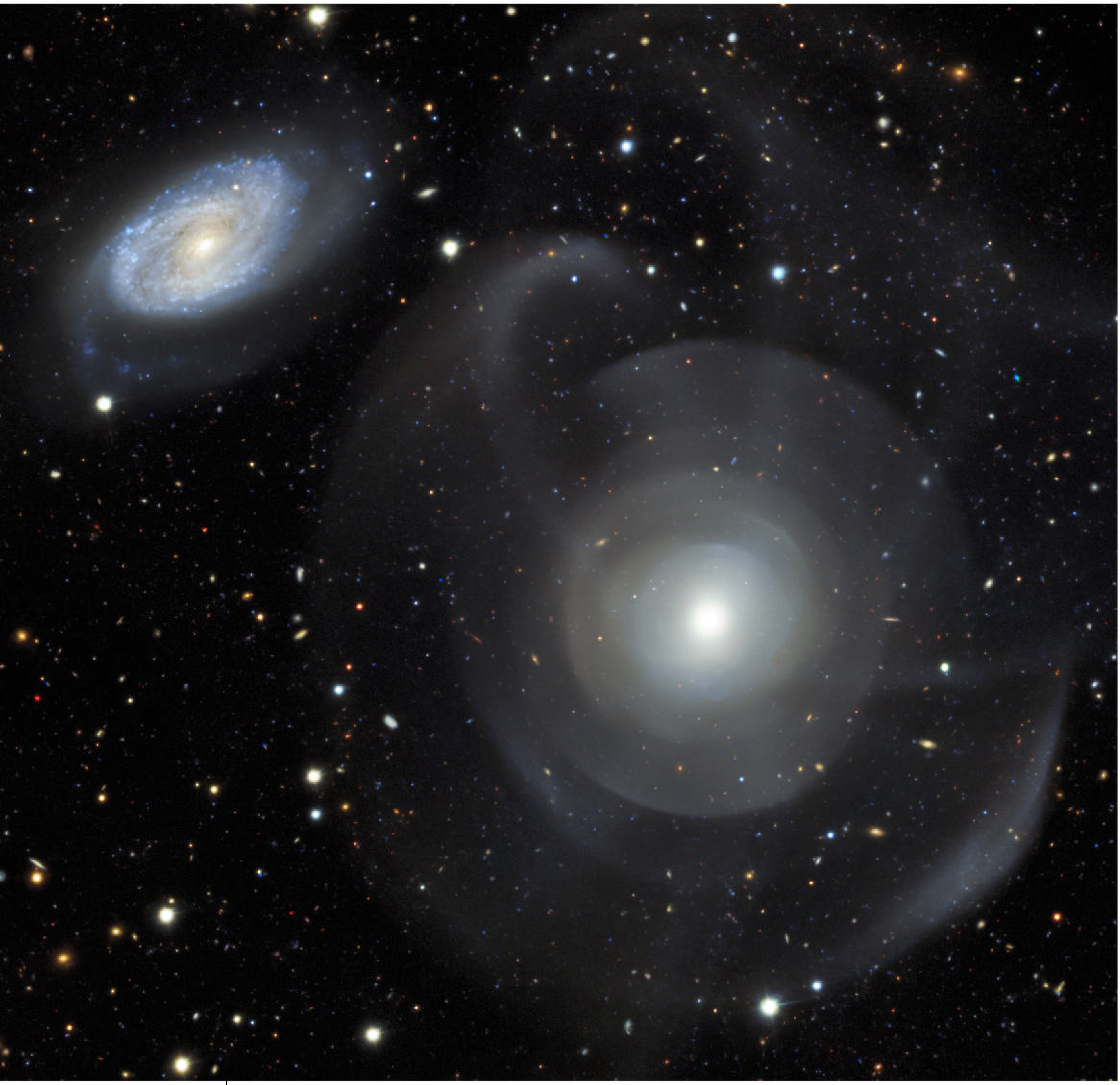
6. ON ITS WAY

Two weeks after launch, JWST was around 650,000 miles (1 million kilometers) from Earth and traveling to the L2 Lagrange point. This image captures the telescope from Yellow Springs, Ohio, the night of Dec. 7, roughly 15 hours before JWST finished deploying its primary mirror. The series comprises one-minute exposures taken every two minutes with a 12-inch scope. **• *John Chumack***

7. LYND'S VESPERS

LBN 587 is an emission region in Cepheus recorded by Beverly Lynds in her 1965 catalog of bright nebulae (a companion to her earlier dark nebulae catalog). This imager used 18 hours and 45 minutes of exposure time with a 4.2-inch scope, rendering the nebulae in the Hubble palette and the star field in LRGB. **• *Emil Andronic***

SEND YOUR IMAGES TO: *Astronomy* Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@astronomy.com.**



SWIMMING WITH THE FISH

Most observers view elliptical galaxies as boring, relatively featureless objects. And at first glance, NGC 474 in Pisces the Fish seems to fit the stereotype. But deep images reveal intricate structures that should put the kibosh on the dull reputation of ellipticals. The outskirts of NGC 474 resolve into multiple shell-like structures and tidal tails containing hundreds of millions of stars. Astronomers suspect these features arise from recent mergers with infalling dwarf galaxies as well as interactions with NGC 470, the spiral companion located to the big galaxy's upper left. NGC 474 spans about 250,000 light-years and lies roughly 100 million light-years from Earth. Scientists took this portrait with the 4-meter Victor M. Blanco Telescope on Cerro Tololo in Chile. DES/DOE/FERMILAB/NCSA & CTIO/NOIRLAB/NSF/AURA

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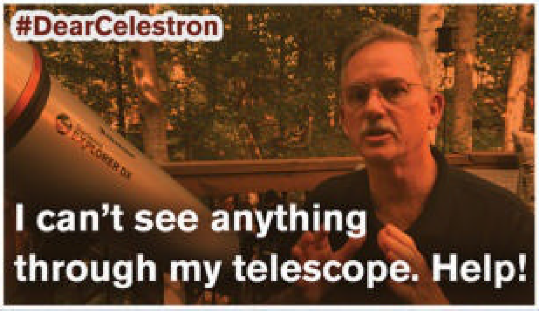
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June 2022

The evening sky awakens

Evenings haven't offered much to planet observers in 2022. But the first signs of change arrive in June. **Saturn** pokes above the eastern horizon around 11 P.M. local time as the month opens and rises 30 minutes earlier with each passing week. The planet lies in eastern Capricornus, some 2° north and a little east of the Sea Goat's brightest star, magnitude 2.8 Delta (δ) Capricorni. Saturn shines at magnitude 0.5 and appears eight times brighter than Delta.

It's always worth observing the ringed world with your telescope. Just be sure to wait until it climbs well above the horizon so you can view it through less of Earth's turbulent atmosphere. Even a small scope reveals Saturn's 18"-diameter disk surrounded by a ring system that spans 40" and tilts 12° to our line of sight. Also watch for the planet's brightest moon, 8th-magnitude Titan, which shows up through any instrument.

You'll need to wait a solid three hours after Saturn rises before another planet appears. **Jupiter** comes up around 2 A.M. local time June 1 followed five minutes later by **Mars**. The two worlds stand 1.4° from each other, about twice as far apart as they were when they were in conjunction May 29. The two separate quickly in June, with Jupiter rising nearly two hours earlier by month's end while Mars gains only 15 minutes.

Both planets start the month in Pisces, but the Fish can't hold them. Mars heads eastward quickly, passing into Cetus the Whale on June 3 before returning to Pisces six days later. Jupiter remains in Pisces until it enters the Whale's domain June 25. It may seem strange that these two worlds spend part of the month in Cetus, a non-zodiacal constellation. But the ecliptic passes close to the Pisces-Cetus border, and both planets lie more than 1° south of the ecliptic this month.

Jupiter shines brilliantly at magnitude –2.3 and stands out in this region of relatively unimpressive stars. The giant world appears more than 10 times brighter than ruddy Mars, which still looks quite impressive at magnitude 0.5.

The best telescopic views of these worlds come when they stand high above the horizon an hour or two before twilight begins. Jupiter's disk spans 39" at midmonth and displays a wealth of atmospheric detail. Mars appears 7" across and should show some subtle surface markings during moments of good seeing.

Venus begins June against the backdrop of Aries the Ram before crossing into Taurus the Bull after midmonth. The inner planet shines brilliantly at magnitude –3.9 and dominates this part of the sky. Venus rises nearly three hours before the Sun and makes a spectacular sight well into twilight.

Unfortunately, a telescope doesn't add much to the view. The planet's 13"-diameter disk shows an 82-percent-lit phase in mid-June.

You'll have to search harder to find **Mercury**. The innermost planet hangs low in the east-northeast during morning twilight this month. It reaches greatest elongation June 16, when it lies 23° west of the Sun and 10° above the horizon an hour before sunrise. The magnitude 0.5 world stands out against the background stars of Taurus.

A telescope reveals Mercury's disk, which appears 8" across and about one-third lit at greatest elongation. It looks a bit more impressive around June 8, however, when the world spans 10" and the Sun illuminates 20 percent of its Earth-facing hemisphere.

The starry sky

If you look to the east after darkness falls this month, the spectacular constellation Scorpius the Scorpion dominates the sky. Its bright stars form a pattern that reminds many skygazers of an arachnid, though others think it looks more like the mirror image of a question mark. The Scorpion's head and abnormally short claws lie at the constellation's northwestern edge, to the left as it rises. (The rest of the claws now belong to the neighboring constellation Libra the Scales.)

An event in this part of Scorpius played a significant role in astronomical history. It was here, in 134 B.C., that the great Greek astronomer Hipparchus observed a "new star," or nova. Chinese astronomers also recorded this nova.

The object's appearance had a profound effect on Hipparchus. He wondered how often such novae burst on the scene, and whether individual stars could move. This inspired him to compile a star catalog containing 1,080 entries.

Hipparchus' catalog formed the basis of Ptolemy's masterwork, *Almagest*, compiled nearly three centuries later. Sadly, Hipparchus' original catalog has been lost. But modern researchers have found that the celestial globe forming part of the Roman statue known as the Farnese Atlas has constellation outlines that match their positions in Hipparchus' time. Many scientists think the sculpture was based on the catalog, or on one of Hipparchus' globes.

The catalog's main claim to fame came when Hipparchus compared his star positions with those from an earlier catalog and noticed a systematic shift in star positions. He had discovered precession — the change in the apparent directions of the stars as a result of the gravitational pulls of the Sun and Moon causing Earth's axis to wobble. Precession makes the direction of Earth's axis trace out a circle on the celestial sphere having a diameter of 47° and a period of about 25,800 years. It's a nice tidbit to ponder as you look at the Scorpion this month.

STAR DOME

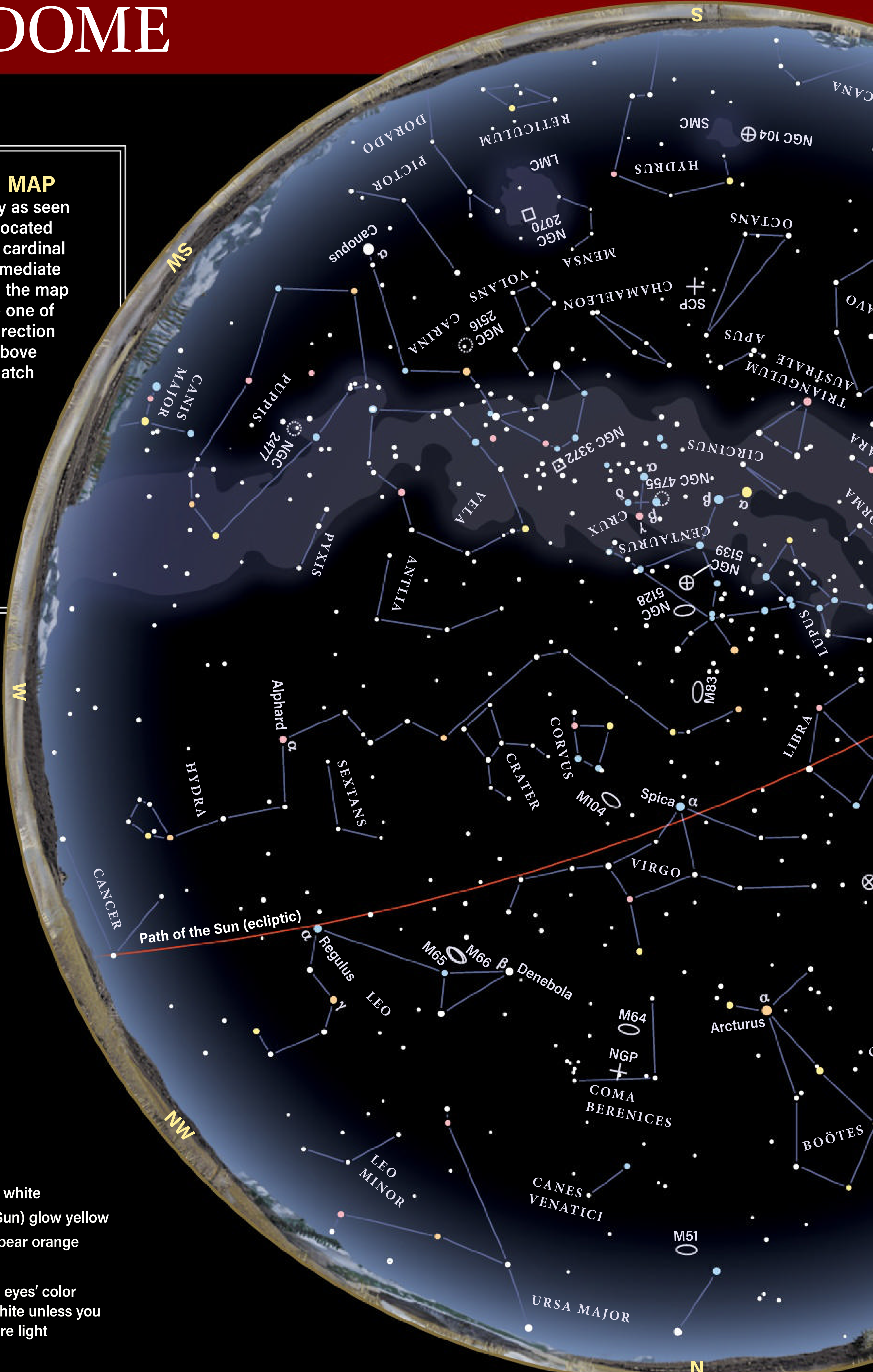
HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. June 1
8 P.M. June 15
7 P.M. June 30

Planets are shown at midmonth



S
SW
W
NW
N
DORADO
RETICULUM
SMC
NGC 104
HYDRUS
PICTOR
LMC
NGC 2070
OCTANS
Canopus
α
MENSA
VOLANS
CHAMAELEON
SCP
CARINA
NGC 2516
APUS
CANIS MAJOR
PUPPIS
TRIANGULUM AUSTRALE
NGC 2477
NGC 3372
CIRCINUS
NGC 4755
VELA
CRUX
CENTAURUS
PYXIS
ANTLIA
NGC 5139
NGC 5128
LUPUS
M83
Alphard
α
HYDRA
SEXTANS
CRATER
CORVUS
LIBRA
M104
Spica
α
VIRGO
CANCER
Path of the Sun (ecliptic)
α
Regulus
LEO
γ
M65
M66
β
Denebola
M64
Arcturus
α
NGP
COMA BERENICES
BOÖTES
LEO MINOR
CANES VENATICI
M51
URSA MAJOR

MAP SYMBOLS

◌ Open cluster
⊕ Globular cluster
☐ Diffuse nebula
⌖ Planetary nebula
⬭ Galaxy

STAR MAGNITUDES

● Sirius

●	0.0	•	3.0
●	1.0	•	4.0
•	2.0	·	5.0

STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

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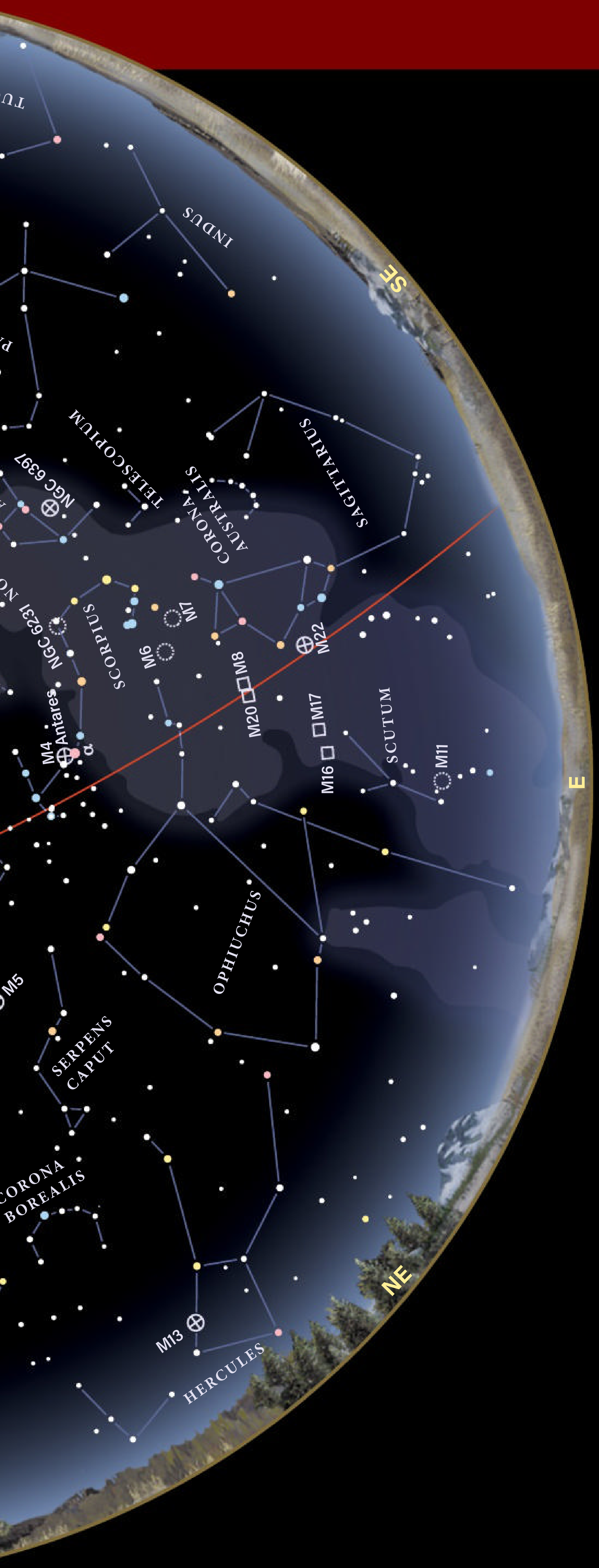
INDUS
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NGC 6397
CORONA AUSTRALIS
SAGITTARIUS
SCORPIUS
NGC 6231
M7
M6
M8
M20
M22
M4
Antares
α
M17
M16
SCUTUM
M11
E
OPHIUCHUS
M5
SERPENS CAPUT
CORONA BOREALIS
NE
M13
HERCULES

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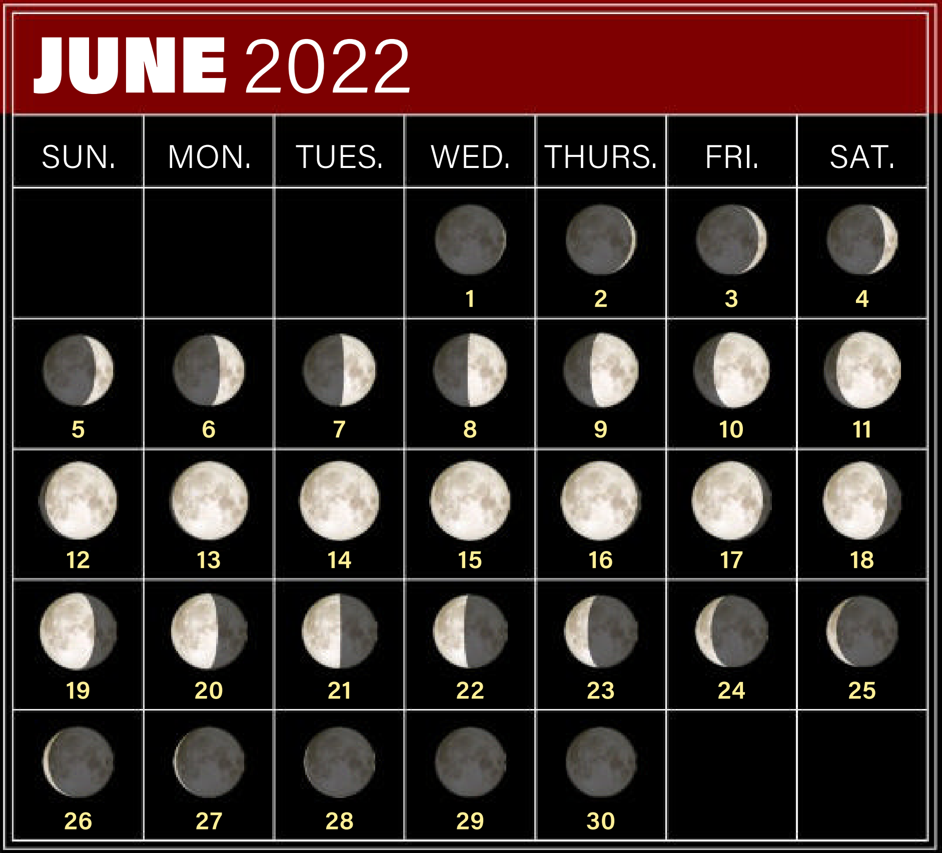

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 The Moon passes 0.1° north of dwarf planet Ceres, 21h UT

2 The Moon is at apogee (406,192 kilometers from Earth), 1h13m UT

3 Mercury is stationary, 0h UT

5 Saturn is stationary, 14h UT

7 ◐ First Quarter Moon occurs at 14h48m UT

11 Venus passes 1.6° south of Uranus, 13h UT

14 ○ Full Moon occurs at 11h52m UT

The Moon is at perigee (357,432 kilometers from Earth), 23h23m UT

16 Mercury is at greatest western elongation (23°), 15h UT

18 The Moon passes 4° south of Saturn, 12h UT

19 The Moon passes 0.7° south of asteroid Vesta, 8h UT

20 The Moon passes 4° south of Neptune, 17h UT

21 ◑ Last Quarter Moon occurs at 3h11m UT

Winter solstice occurs at 9h14m UT

The Moon passes 3° south of Jupiter, 14h UT

22 The Moon passes 0.9° south of Mars, 18h UT

23 Mercury passes 3° north of Aldebaran, 14h UT

24 The Moon passes 0.05° south of Uranus, 22h UT

26 The Moon passes 3° north of Venus, 8h UT

27 The Moon passes 4° north of Mercury, 8h UT

28 Neptune is stationary, 23h UT

29 ● New Moon occurs at 2h52m UT

The Moon is at apogee (406,580 kilometers from Earth), 6h08m UT

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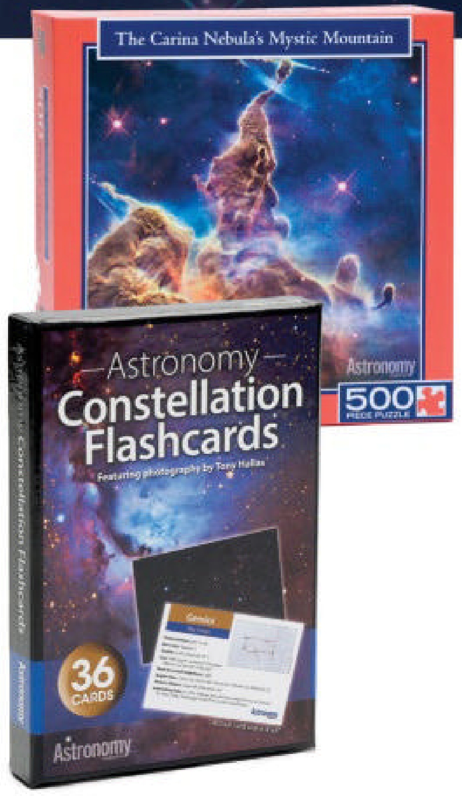
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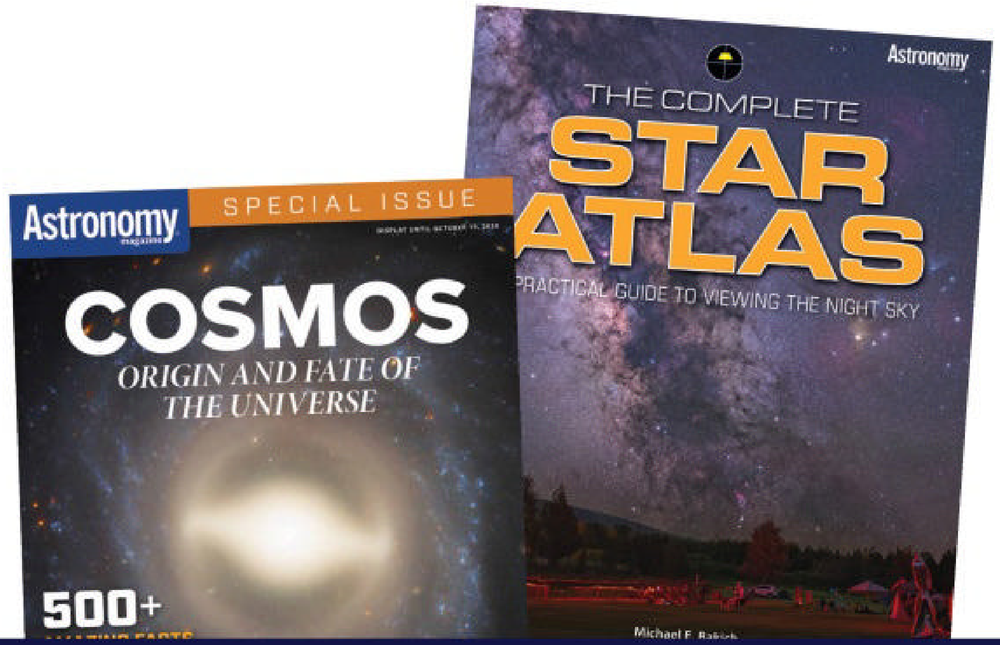
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